JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA.

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXXXV. MAY, 1893. NO. 5

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DUTY TRIAL OF A PUMPING ENGINE, BUILT BY THE GEO. F. BLAKE MANUFACTURING COMPANY.

BY F. W. DEAN, S.B.

Late in 1889, the city of Newton, decided to add to their pumping plant a new engine and two new boilers, and the writer was engaged as consulting engineer. He advised the Water Board to accept the bid of The Geo. F. Blake Manufacturing Company, not only because the price was the lowest, but because it was evident that their offer was for the highest type of compound engine. It was true that no engine like this had been built, but he had sufficient confidence in the builders to believe that they would succeed in designing a durable and highly efficient engine. The result proved the wisdom of the choice, for after some mishaps and experimentation incident to a first machine, the

pumping engine emerged a very economical and successful piece of mechanism.

There is little to be said beyond that contained in the report of the official test of the Water Board, except as to the reasons why the engine gave a higher duty on this test than on that conducted by Professor Peabody. This was due chiefly to changing the supply of the live steam entering the re-heater, and doubtless to the valves having had time to wear to more accurate fits. The re-heater live steam originally came by an independent small pipe of considerable length from the bottom of the steam drum, thus conveying all condensation that had accumulated as far as the bottom of the drum, and all that formed in the small pipe to the re-heater. Before making the official test the re-heater live steam was taken from the main steam pipe as near the engine as possible, and this arrangement became permanent. Moreover, as five months had elapsed between the two tests it is evident that everything was in the better order at the later date.

Concerning the lower efficiency of the mechanism during the second test, the reason was doubtless due to air entering the suction pipe, coupled with the greater speed of the pump. At times sufficient air would enter to make very loud knocks. It was caused by the lowness of the water in the well, and this could not be raised. When the air entered the pump, indicator cards showed great fluctuations in pressure, but when there was water enough in the well the pump diagrams were as smooth as those shown in Professor Peabody's report. The harmful condition existed so much of the time that there was without doubt much energy wasted in the pump end.

The boiler performance was better on the second test, although better coal was used on the first test. This was due to experience gained in firing during the interval of five months.

* * * The contract required an engine capable of pumping 5,000,000 gallons in twenty-four hours, with a guaranteed duty of 115,000,000 foot-pounds of work by the consumption of a quantity of water evaporated into dry

steam, the equivalent of which is 1,100 pounds of water evaporated from and at 212° F. The method of computing this duty is fully explained in the specifications and is as follows: "The area of the plunger(s) in square feet will be multiplied by the pressure in pounds due to the total lift in feet, which will be obtained from the average reading of a correct pressure-gauge attached to the force main near its connection to the pump, to which will be added the pressure due to the difference of level between the zero of the gauge and the water in the pump well, the product thus obtained will be multiplied by the total number of feet traveled by the plungers on their discharging strokes. This product equals the total work in foot-pounds. The amount of water evaporated by the boilers during the trial will be reduced to an equivalent number of pounds of water evaporated from and at 212° F. The total work in foot-pounds divided by this equivalent evaporation and the quotient multiplied by 1,100 will be the duty of the engine in foot-pounds per specified unit of water evaporated into steam."

Soon after the contract was made the American Society of Mechanical Engineers advocated, through a committee instructed to devise a standard method of conducting duty trials of pumping engines, the computation of duty upon the consumption by the engine of 1,000,000 units of heat. In consequence of this, the duty has been computed upon this basis as well as upon the other.

The contract also embraces the installation of two boilers of the locomotive type having the Belpaire system of staying the crown sheets. Each boiler was to be sufficiently large to easily furnish steam for the engine to full power. Through the liberality of the contractors, The Geo. F. Blake Manufacturing Company, these boilers were designed to safely carry 150 pounds by gauge to the square inch, although the usual working pressure was to be less than 130 pounds. These boilers were guaranteed to evaporate no less than eleven pounds of water per pound of combustible reduced to the equivalent of feed-water at 212° and evaporation at that temperature.

The engine is a new type of cross compound fly-wheel horizontal pumping engine with the Corliss type of valve gear, designed and built by the contractors, The Geo. F. Blake Manufacturing Company. It consists of one high-pressure cylinder and one low-pressure cylinder side by side and two double-acting horizontal pumps similarly arranged. Each pump has its axis coincident with that of one steam cylinder, and the companion steam piston and pump rods are both keyed to a cross-head about midway between the steam and pump ends of the engine, there being therefore two cross-heads. These cross-heads slide upon guides which form tie rods between the steam cylinders and pumps.

Near each steam cylinder there is a vertical beam working on horizontal bearings formed in a lower bed plate. These beams are operated by links passing from journals on the cross-heads to pins in the upper ends of the beams, and motion is transmitted to the fly-wheel shaft by means of connecting rods passing from pins near the middle of the beams to the pins of cranks on the ends of the shaft. The shaft rotates in boxes formed in the bed plate before mentioned. The cranks are at right angles to each other, the low-pressure crank leading.

The valve gear possesses novel features. Among them may be mentioned the absence of springs from the latching mechanism, and the operation of this mechanism by a special eccentric for each cylinder. There is a high speed centrifugal governor which varies the cut-off through a wide range. The inlet and exhaust valves of the low-pressure cylinder are driven by different eccentrics.

The cylinders are jacketed by steam on its way to the steam chests, and between the cylinders there is a tubular re-heater, the re-heating being done by live steam taken from the main steam pipe near the engine.

There is a coil feed-water heater in the exhaust pipe of the low-pressure cylinder, and the main feed pump forces the water through this coil to the boiler. Another pump forces the water formed by the condensation of the live steam in the re-heater to the boiler. The condensation in the main steam pipe, that in each jacket, and that in the

exhaust steam side of the re-heater, are trapped and wasted.

The air pump is vertical and single-acting, and it and both feed pumps are operated from arms on an extension of the low-pressure beam axis pin.

The main pumps are, as before stated, double-acting and are provided with a large valve area.

PRELIMINARY TEST.

A preliminary test of three hours' duration was made a few days before the official test, as prescribed in the American Society Code, in order to establish working temperatures, the conditions of working being substantially the same as during the official test. These temperatures were properly modified to suit the slightly changed conditions during the test. The modifications consisted in reducing the average temperature of the re-heater drain supply at the boiler 1°·11, and reducing that of the main feed at the boiler 4°·6. The higher temperature of the main feed might have been used in computing the results of the official test, had it not been for the fact that the contractor preferred to run this test with a vacuum one inch greater than during the preliminary test. The hot well temperature was thus reduced some 6°. Under these circumstances it was thought an unjustifiable assumption to suppose that the total heat effect of the steam during the official trial would be correctly represented, considering the different vacuums in the two trials, by using the main feed temperature as determined during the preliminary trial. This is in the direction of conservatism, and is one reason for supposing that the engine can give even higher duties than those here tabulated. During the official test the main feed was taken from the pump well and the average temperature was 59°·47. This water passed through the feed-water heater and left the engine only 3°·81 lower than during the preliminary test, and entered the boiler as before stated only 4°·6 lower.

THE OFFICIAL TRIAL.

The fires in No. 2 boiler, which had been thoroughly cleaned, were lighted some four hours before the trial was

to begin. The engine was run also for about an hour before the trial, thus heating both boiler and engine to their normal working temperatures. The engine was stopped and the fires were drawn. New fires were immediately started and the pressure of steam and height of the water accurately taken. As soon as practicable, the engine was started and the boiler test was considered as begun, the time being 9.42 A.M., September 30, 1892.

The feed-water weighing also began, the re-heater drain was running to waste, and each man was at his post. At precisely 10 A.M. the feed-water level in the lower tank, and the water level in the boiler were accurately noted and the re-heater drain turning into a hogshead of cold water placed upon scales. Previous to beginning the boiler test all pipes in both boiler and engine rooms which could convey either water or steam to or from any point so as to vitiate the accuracy of the results, were disconnected, and it was ascertained that no valves leaked. In connection with this it may be stated that all pressures were taken with nice test gauges which were known to be correct, all temperatures with high-grade tested thermometers and all indicators were provided with tested springs. All scales used for weighing coal and water were made correct with standard weights.

The pressure of the water in the force main was taken every ten minutes and the distance below the point at which this pressure existed was measured by an adjusted scale resting upon a float upon the water in the pump well. It was read simultaneously with the pressure-gauge. The scale also showed the total suction lift of the pump, and this was read every ten minutes. The total pressure against which the pump acted was computed from the gauge and float readings and the weight of water corrected for its temperature.

On account of the scarcity of water in the pump well the suction lift was excessive and did not permit the pumps to work advantageously. The friction of the pump was much more than in a previous test carried out by Prof. C. H. Peabody. A portion of the extra friction was doubtless

caused by the greater speed of the engine in this test. The average number of revolutions per minute in Professor Peabody's test was 37·695, and in the official test 39·115.

Indicator diagrams were taken from the steam cylinders every twenty minutes, two Crosby indicators being used on the high-pressure cylinder and two Thompson indicators on the low-pressure cylinder. Indicator diagrams were occasionally taken from the pumps with Thompson indicators.

Pressures were taken every twenty minutes at the boiler, at the throttle, and on the steam supply end of the re-heater. The counter was read every twenty minutes. Temperatures were taken, every twenty minutes, of the feed-water before passing the heater; immediately after passing the heater; of the re-heater drain immediately after leaving the re-heater, and about four feet beyond; of the feed-water where it entered the boiler; and of the flue temperatures during the first nine hours and last two hours of the test. Only one reading was taken at the hot-well.

No calorimetric observation of the quality of the steam were taken, as this was done by Professor Peabody a few months before his results being accepted as applicable to this test. The calorimeter was applied near the throttle, and the moisture was found to be seven-tenths of one per cent. This was held to be due to condensation in the steam drum and steam pipes, which were rather long. The boiler was supposed to furnish dry steam.

As the time approached for ending the test the fire was burned down as low as practicable while keeping the pressure nearly constant, and the water in the boiler at its normal height. At the end of twenty-four hours the height of the feed-water in the lower barrel was marked, the water in the boiler being at the original height, and the jacket drain turned to waste. The engine test was then completed. The engine was immediately stopped, the water brought to the original boiler test level, with the original pressure and the boiler test ended. The fire was then drawn and the unconsumed coke picked out and deducted from the coal fed into the fire boxes. The level of the feed-water in the lower tank was noted at the end of the boiler test.

After the test was over the quantities of water necessary to bring the water in the lower feed tank to the original engine test and boiler test levels were weighed.

It is obvious that the engine test was shorter than that of the boiler, and the coal quantity to be credited to the engine was ascertained by making it proportional to the number of heat units which passed to the engine from the boiler during the engine test.

In the table which follows it will be seen that the amount of steam used per hour per indicated horse-power is given with the moisture deducted in order to compare this result with similar results from other engines. While it is not strictly proper to make this deduction, the result is probably more nearly correct than if the deduction were not made. It is true that the heat in the moisture passes through the engine and may do good somewhere, but considering the fact that the moisture is known to do harm, and that the engine is not responsible for it, the benefit from the heat is doubtful. Little or none of it can flash into steam during its course because heat of vaporization is so much greater than heat of liquid. This discussion seems necessary in view of the fact that the steam consumptions given, place this engine among the most economical in the world.

The following tables give the principal dimensions of the engine and boilers with the results of the trial in detail:

Dimensions of the Engine.

(1) Type, cross compound, fly-wheel	
(2) Diameter of high-pressure cylinder, . . .	21 inches.
(3) Diameter of low-pressure cylinder, . . .	42 inches.
(4) Diameter of each pump plunger, ...	13½ inches.
(5) Diameter of piston and plunger rods, . .	4 inches.
(6) Stroke of all pistons and plungers, . . .	40 inches.
(7) Diameter of one single-acting air pump, .	26 inches.
(8) Stroke of same, ...	12 inches.
(9) Diameter of single-acting plunger feed pump, ...	4½ inches.
(10) Stroke of same, ...	6 inches.
(11) Diameter of pump plunger for returning re-heater drain to boiler, ...	2 inches.

(12) Stroke of same,	6 inches.
(13) Ratio of volume of low-pressure cylinder to high-pressure cylinder,	4 to 1
(14) Volume of pump cylinder corresponding to one displacement of plunger average,	3·167 cubic feet.
(15) Diameter of suction main,	24 inches.
(16) Diameter of force main at engine house,	24 inches.

Dimensions of the Boiler.

(17) Smallest inside diameter of shell,	84 inches.
(18) Inside length of fire box,	8 feet.
(19) Inside width of fire box (twice 3 feet 5¼ inches),	6 feet 10½ inches.
(20) Length of combustion chamber,	4 feet.
(21) Length of tubes,	16 feet.
(22) Diameter of tubes, outside,	3 inches.
(23) Number of tubes,	170
(24) Length of grate,	7 feet.
(25) Width of grate (twice 3 feet 5¼ inches),	6 feet 10½ inches.
(26) Heating surface,	2,310 square feet.
(27) Grate surface,	48·125 feet.
(28) Ratio of grate to heating surface,	48·00

Engine Test.

(29) Duration of trial,	24 hours.

Average Pressure, etc.

(30) Steam pressure at the boiler by gauge,	125·60 pounds.
(31) Steam pressure at the throttle valve by gauge,	122·31 pounds.
(32) Pressure of atmosphere by barometer,	14·72 pounds.
(33) Absolute steam pressure at boiler,	140·32 pounds.
(34) Absolute steam pressure at throttle valve,	137·03 pounds.
(35) Vacuum by gauge,	27 inches.
(36) Weight of one cubic foot of water at 59°·5 F.,	62·37 pounds.
(37) Water pressure in gauge chamber,	96·83 pounds.
(38) Difference in level of gauge and water in pump well,	21·14 feet.
(39) Corresponding pressure,	9·156 pounds.
(40) Total water pressure (head),	105,986 pounds.
(41) Minimum suction lift,	21·84 feet.
(42) Maximum suction lift,	23·23 feet.

Average Temperatures.

(43) Of engine room,	75°·96 F.
(44) Of external air,	60°·50 F.

(45) Of feed-water at boiler, as deduced from preliminary test,	129°·90 F.
(46) Of re-heater drain at re-heater,	341°·40 F.
(47) Of re-heater drain at boiler as deduced from preliminary test,	280°·30 F.
(48) Of water in pump well,	59°·50 F.

Feed Water.

(49) Total water pumped into boiler during engine test,	84,491 pounds.
(50) Moisture in steam at throttle,	0·007
(51) Steam used in cylinders of engine,	79437·12 pounds.
(52) Steam used in re-heater,	5053·88 pounds.
(53) Steam used per hour per indicated horse-power, excluding moisture,	13·97 pounds.
(54) Steam used per hour per indicated horse-power, including moisture,	14·07 pounds.

British Thermal Units.

(55) Per pound of steam used in the cylinders,	1093·05
(56) Per pound of steam used in the re-heater,	870·55
(57) Total used in the cylinders and re-heaters,	91,228,399
(58) Total used in the cylinders and re-heater in twenty-four hours,	91,228,399
(59) Supplied by boiler per pound of steam from 129°·9 F. to 140·32 pounds absolute,	1091·56
(60) Total supplied by boiler in twenty-four hours,	92,215,632
(61) Total supplied per pound of coal,	10816·8
(62) Total supplied per minute per indicated horse-power,	253·14
(63) Efficiency of the engine,	16·9 per cent.

Average Powers Developed.

(64) Total number of revolutions in twenty-four hours,	56,326
(65) Average number of revolutions per minute,	39·115
(66) Average mean effective pressure in high-pressure cylinder,	42·44 pounds.
(67) Average mean effective pressure in low-pressure cylinder,	12·50 pounds.
(68) Horse-power developed by high-pressure cylinder,	114·3
(69) Horse-power developed by low-pressure cylinder,	136·24
(70) Horse-power developed by both cylinders,	250·27
(71) Percentage of total power developed in high-pressure cylinder,	45·6 per cent.

(72)	Percentage of total power developed low-pressure cylinder,	54·4 per cent.
(73)	Horse-power of water plungers,	229·23
(74)	Efficiency of mechanism,	91·6 per cent.
(75)	Steam accounted for by indicator at cut-off high-pressure cylinder,	8·78 pounds.
(76)	Steam accounted for by indicator at release, high-pressure cylinder,	10·35 pounds.
(77)	Steam accounted for by indicator at cut-off low-pressure cylinder,	9·20 pounds.
(78)	Steam accounted for by indicator at release, low-pressure cylinder,	11·41 pounds.
(79)	Proportion of above to feed-water consumption, at cut-off high-pressure cylinder,	63 per cent.
(80)	Proportion of above to feed-water consumption, at release high-pressure cylinder,	74 per cent.
(81)	Proportion of above to feed-water consumption at cut-off low-pressure cylinder,	66 per cent.
(82)	Proportion of above to feed-water consumption, at release low-pressure cylinder,	82 per cent.
(83)	Percentage of total steam, used by cylinders,	94·02 per cent.
(84)	Percentage of total steam used by reheater,	5·98 per cent.

Boiler Test.

(85)	Duration,	24·38 hours.

Average Pressures.

(86)	Steam pressure at boiler by gauge,	125·60 pounds.
(87)	Atmospheric pressure by barometer,	14·72 pounds.
(88)	Absolute steam pressure,	140·32 pounds.
(89)	Force of draught, inches of water,	·35 inches.

Average Temperatures.

(90)	Of external air,	60°·5 F.
(91)	Of fire room,	81°·5 F.
(92)	Of escaping gases during the first nine hours,	391° F.
(93)	Of escaping gases during the last two hours,	494° F.

[Note.—The results (75) to (82), both inclusive, are necessarily approximate for the whole test, and indicate steam behavior in a general way only.

(94)	Of feed-water before entering heater, . .	59°·5 F.
(95)	Of feed-water before entering boiler, . . .	129°·9 F.

Fuel.

(96)	Total weight of dry coal consumed, including equivalent of wood, ...	8653·6 pounds.
(97)	Total dry refuse, weight, ...	632·6 pounds.
(98)	Total dry refuse, percentage, ...	7·3 per cent.
(99)	Total combustible weight, ...	8,022 pounds.
(100)	Total combustible percentage, ...	92·7 per cent.
(101)	Total calorific value of one pound of coal by experiment, ...	13,452 B.T.U.
(102)	Total calorific value of one pound of coal by analysis, ...	14,373 B.T.U.

Calorimetric Test of Steam.

(103)	Percentage of moisture in steam, ...	$\frac{7}{10}$ of 1 per cent.

Water.

(104)	Total weight of water pumped into boiler and apparently evaporated, ...	85,011 pounds.
(105)	Equivalent water evaporated from and at 212° F., ...	96,912 pounds.
(106)	Equivalent total heat derived from fuel in British thermal units, ...	93,602,212
(107)	Equivalent water evaporated from and at 212° per hour, ...	3,975 pounds.

Economic Performance.

(108)	Water evaporated per pound of dry fuel from average temperature of feed (129°·9) at average steam pressure (125·6 pounds).	9·91 pounds.
(109)	Equivalent water evaporated from and at 212°, ...	11·19 pounds.
(110)	Equivalent water evaporated from and at 212° per pound of combustible, ...	12·08 pounds.
(111)	Equivalent total heat derived from a pound of dry coal, ...	10816·8 B.T.U.
(112)	Dry coal burned per hour per square foot of grate surface, ...	7·38 pounds.
(113)	Water evaporated per hour per square foot of heating surface from and at 212° F.,	1·51 pounds.

Duties.—Based upon the heat given to each pound of water fed to the boiler:

(114)	Per Newton Basis, ...	125,497,323 ft. lbs.
(115)	Per 100 pounds of coal burned, ...	127,779,469 ft. lbs.

Based upon the heat received and rejected by the engine:

(116)	Per 1,000,000 British thermal units, . . .	119,406,777 ft. lbs.

Analysis of coal used.

KIND OF COAL, GEORGES CREEK, CUMBERLAND.	*Per Cent.*
Moisture,	·58
Carbon,	79·40
Hydrogen,	5·11
Oxygen,	3·80
Nitrogen,	1·25
Ash,	9·24
Volatile sulphur,	·62

The duty on the Newton Basis is 125,497,323 foot-pounds, or $9\frac{12}{100}$ per cent. above the guaranteed duty of 115,000,000 foot-pounds.

The boiler evaporated 12·08 pounds of water per pound of combustible, from and at 212° F., and therefore exceeded the guarantee of 11 pounds by 10·98 per cent.

Although the specifications require a test of each boiler there appears to be no reason for another test as the boilers are exact duplicates.

The engine runs smoothly at all times and will always be very economical. Whether looked upon from the standpoint of excellence of design, workmanship, durability or stability, the engine is second to no horizontal pumping engine in the country.

The results of the boiler trial show the boiler to be among the most economical on record, and this high degree of economy will be maintained indefinitely.

CAPACITY OF PUMPS.

The amount of water displaced by the pump plungers during the test, no allowance being made for slip, was 5,339,141 gallons in twenty-four hours. This less four per cent. for slip equals 5,123,575 gallons in twenty-four hours. As no weir measurement could be made of the qantity of water pumped the actual slip is not known. No method* of ascertaining slip other than by weir measurement can give a result which is more than an assumption, and as four per cent. is rarely reached, it is safe for the city's interest to use this.

* A Venturi tube might have been used in the discharge pipe, giving an error of about one per cent. F. W. D.

TEST OF A ONE HUNDRED HORSE-POWER GAS ENGINE USING PRODUCER GAS.

By H. W. Spangler.

About a year ago the makers of the Otto gas engine, Messrs. Schleicher, Schumm & Co., stated that they were then completing a 100 horse-power gas engine, and that their plant was run on producer gas and the engine would be at our service to make a test to determine the amount of coal used per horse-power. Unfortunately this engine was not completed before the end of the college year, so that it was practically impossible to carry out the test at that time. Later in the year another engine of the same size was under way and was offered to us at a time that we could do the work, and we gladly undertook to make as full a test as the means then at hand would allow.

The data were taken by students of the Mechanical Engineering Department of the University of Pennsylvania under my direct supervision, and most of the results were worked out by Messrs Head and Wood for a graduation thesis.

The engine tested was nominally a 100 horse-power, two cylinder Otto gas engine, sections of which are shown in *Figs. 1, 2* and *3*. The cylinders are horizontal, one directly over the other. The general type of the engine is very much that of the ordinary Otto. The connecting rod from the upper piston takes hold of the crank pin, while the connecting rod from the lower piston is attached to the upper connecting rod, some distance back of the pin. The arrangement of the admission and exhaust valves is plainly shown in the figures. The gas and air are admitted through the pipes marked, there being a throttle valve on the gas pipe. The supply valves to the cylinders are disc valves, opening inwardly, and which are held on their seat by a light spiral spring. The exhaust valves are flat valves, which are opened by a cam, as is

usual in engines of this type. During the test the relative amounts of air and gas admitted were regulated so that there was as little loss as possible from incomplete combustion.

The engine for testing was set up on the foundation which is usually used at the works for testing large engines before sending them out. The pipe connections for this engine were so made that gas could be used either from the city supply or from the producer, and during the test the joints in the city supply pipe were broken and no gas could get to the mains except such as came from the producer. During the time of the test the engine which runs the factory was disconnected from the pipes carrying the producer gas, and was supplied with gas from the city mains.

A diagrammatic view of the producer is shown in *Fig. 4.*

The producer, which was Taylor's patent, No. 4, consists of a cylindrical shell *D'*, lined with fire brick *E*, at the bottom of which was a grate *F*, which could be turned around its centre by means of gearing *G*, extending outside the base of the producer.

Ashes filled the producer from the grate to about six inches above the top of the air pipe *H*, coming out in the centre of the producer.

The air supply for the producer is derived from the positive blower, driven by shafting in the works. The power necessary to drive it was afterwards determined. The air entered the pipe, at the point marked, from the blower and passed directly into the bottom of the first scrubber up through the wet coke, with which the bottom of the scrubber was filled, then through the air pipe *H* under the coal in the producer. As it passed through the producer it converted the carbon of the coal largely into carbonic oxide, then passed through the pipe *I* into the bottom of the top half of the first scrubber where the pipe dipped into a water seal. After passing up through the first scrubber it passed down, up through the second scrubber and then into the gasholder, the course taken by the air from the point that it entered to the point at which it was discharged into the gasholder, being shown by the arrows.

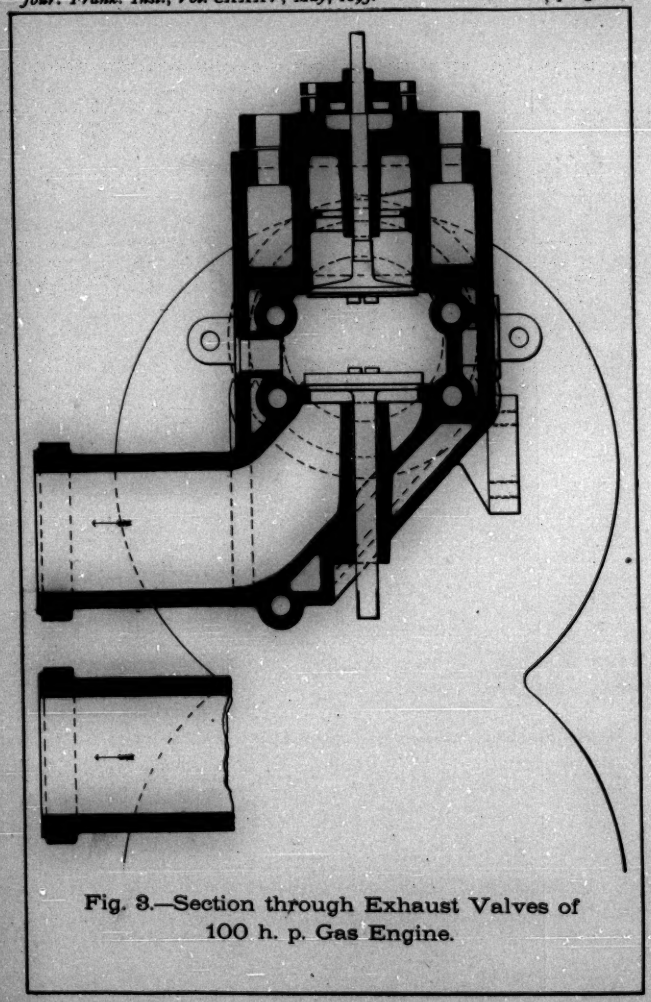


Fig. 3.—Section through Exhaust Valves of 100 h. p. Gas Engine.

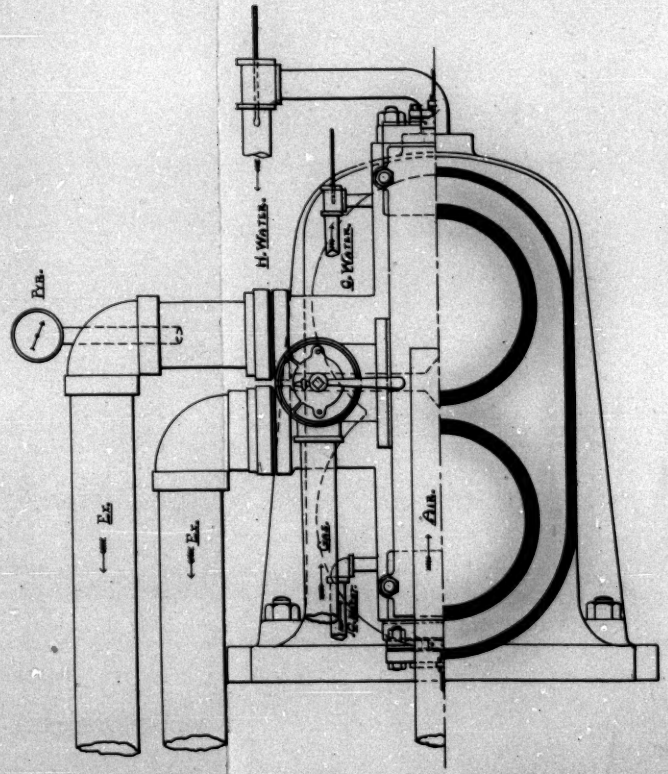


Fig. 2.—Section through Cylinders and End Elevation of 100 h. p. Gas Engine.

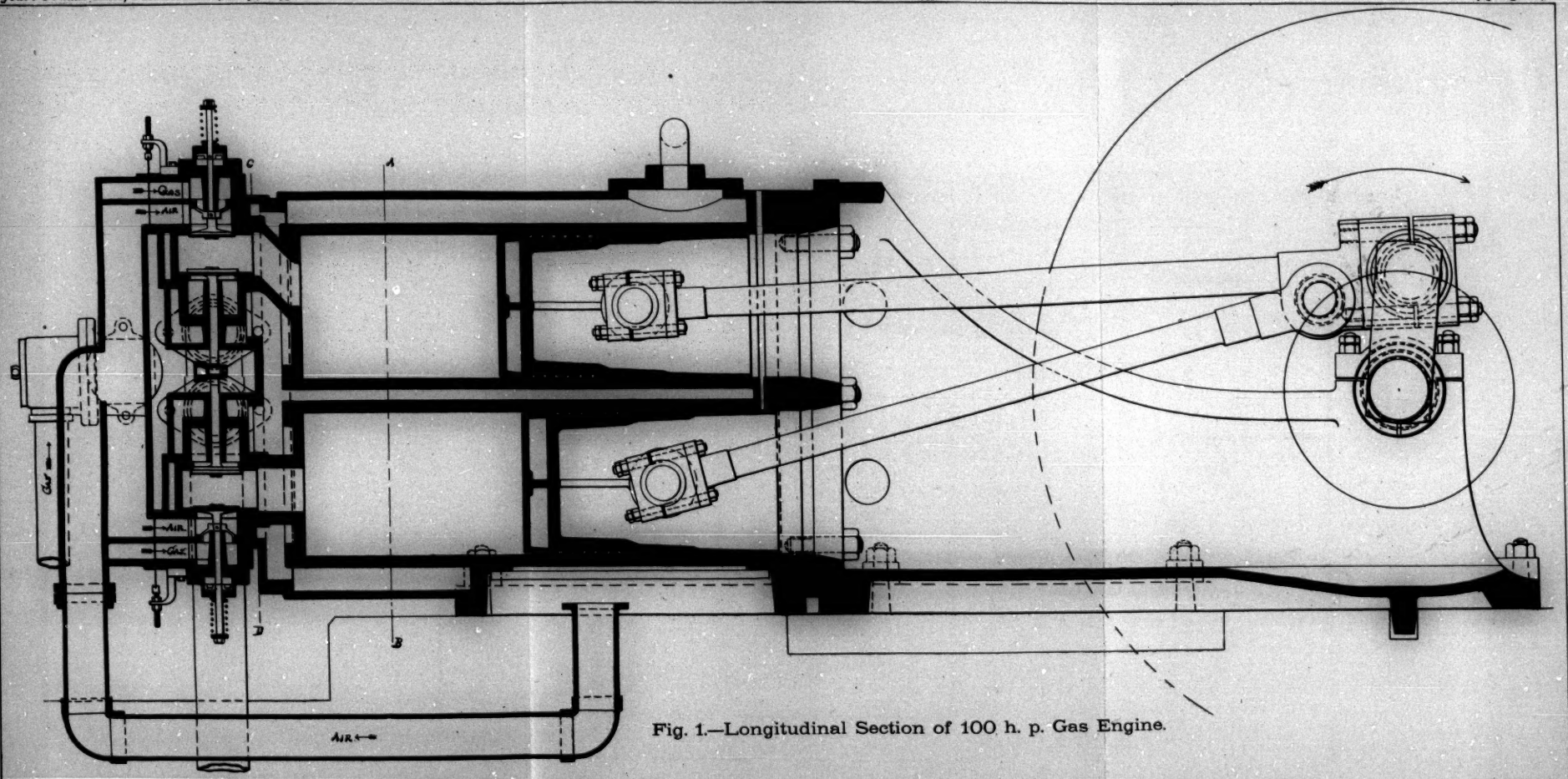


Fig. 1.—Longitudinal Section of 100 h. p. Gas Engine.

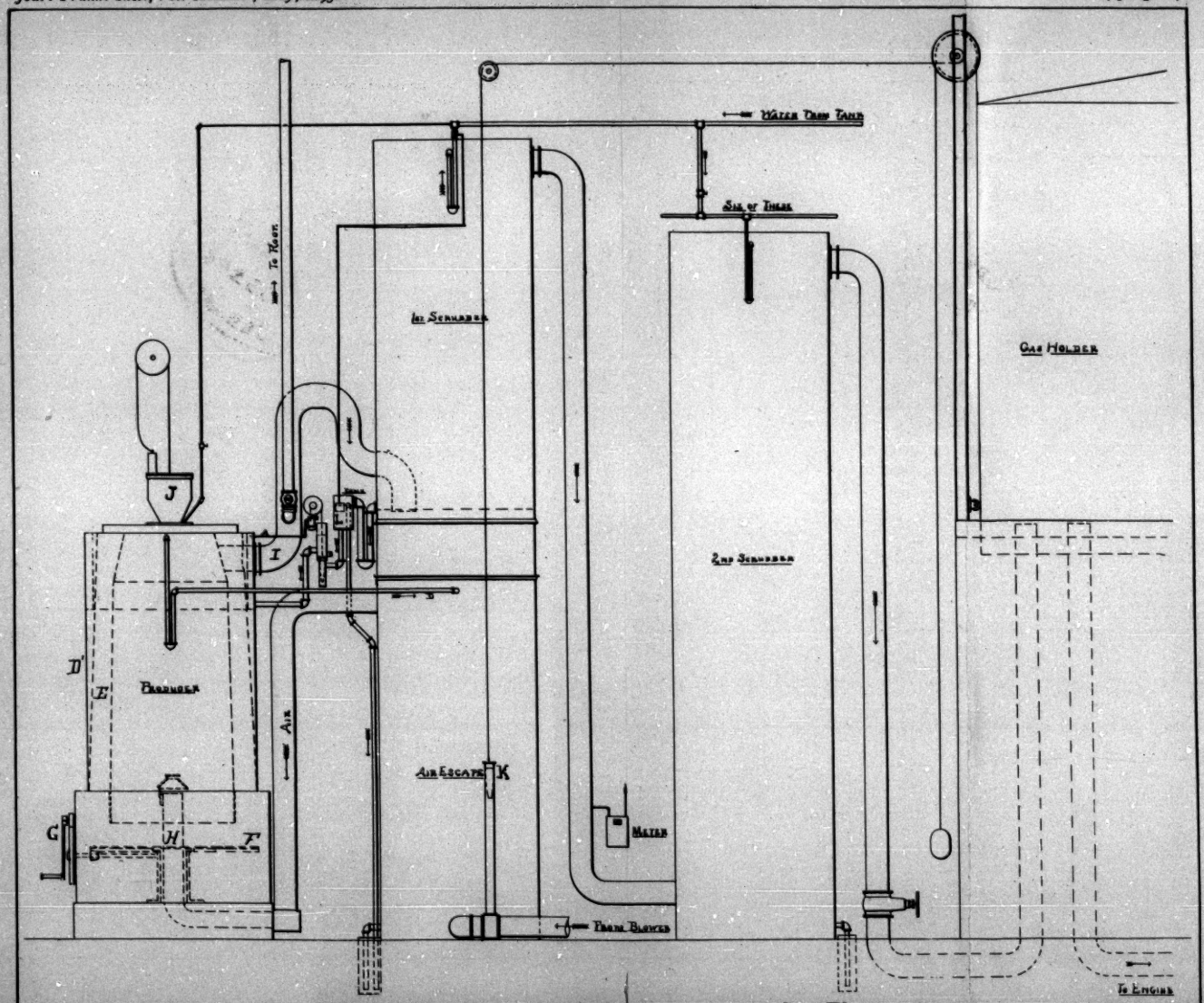


Fig. 4.—Diagrammatic Sketch of Producer Gas Plant.

Coal was fed in through the circular box *J* on the top of the producer, the bottom of which was an inverted cone held up tight by a chain, pulley and weight. The supply of air was regulated by an escape valve *K*, which was closed by the descent of the gasholder.

All the small pipes are water pipes, except the one marked *A*.

The water comes from a tank on the roof, supplying the second scrubber, and continuing to the first, the supply for which is regulated by a float in the small tank *L*. In this manner the scrubbers are cooled and the water seal maintained.

From the small tank *L*, the water flows through the valve *B* into a circular jacket around top of the producer. The valve is governed by the motion of a piston in *C*, which opens *B*, when the temperature of the water in the producer exceeds a fixed height. This was so adjusted that a continuous flow of hot water takes place through the pipe *D* to the top of the lower part of the first scrubber, where it heats and moistens the air before entering the producer, the first scrubber being divided in the middle of its height by an air-tight partition. By this system the steam necessary for the producer is obtained by utilizing the heat which is carried from the bed of fuel by the gas, and by this means the steam boiler usually used in connection with boilers is dispensed with. This method of supplying moisture is the invention of Mr. Paul Winand, of the Otto Works, and a comparison of the following tests with those in which a separate boiler is used for supplying steam shows a decided saving in coal consumed.

During the test the explosion of the gas in the engine was caused by a spark made by the breaking of the circuit of Edison-Lelande cells, a spark coil being in the circuit.

The gas pipe from the producer to the gas bag was eight inches in diameter. The gas bag was a cylinder 3 feet in diameter and 1 foot long, having loose gas-proof ends. A three and one-half inch gas pipe connected the gas bag to the engine.

The method of making the test was as follows:

The coal that was fed to the producer was weighed partly in charges of about 130 pounds, and during a portion of the time the amount used at each firing was noted. Samples of the coal used were taken and afterwards tested under the direction of Prof. Edgar F. Smith, of the University, and was found to have the following composition:

Per Cent.	
4·20 moisture.	
6·88 volatile and combustible,	3·18 per cent. hydrogen.
	84·76 per cent. total carbon.
80·41 fixed carbon.	
8·51 ash.	
0·74 sulphur.	

Samples of the gas in the holder were taken at frequent intervals and tests made of it, some of the tests being complete ones, while others simply showed that the conditions remained about constant.

The pressure and temperature of the gas as it went into the gas bag were noted at regular intervals. Indicator cards were taken from both cylinders every half hour during the test. A supplementary wheel was bolted to one of the fly-wheels of the engine, and on this a prony brake was fitted. Water was allowed to run on the inside of the rim of the wheel and evaporate, and as the details of the test will show, no difficulty was experienced in keeping the load reasonably constant.

The temperature of the water used in the jacket was taken throughout the test, and at regular intervals the quantity of water used every four minutes was run into an iron tank and weighed.

A continuous counter was used to record the number of revolutions of the engine, and a counter was fitted in such a way that the number of times the gas valve opened to admit gas was registered.

A Brown's pyrometer was fitted in the exhaust pipe to determine the temperature of the exhaust gas and provision was made by which samples from the exhaust pipe could be taken for each engine and the gas analyzed.

The test proper extended over three days, while preliminary trials were made on the two preceding days. The

condition of the fire in the producer was noted on the evening of May 4th, by pushing an iron rod from the top of the producer down to the grate, allowing it to remain long enough to become red hot, then marking the two ends of the hot portion, and measuring the thickness of the bed of ashes and of the bed of coal on the rod. The height of the holder was noted, and the plant shut down until the next morning.

On May 5th, the engine was started at 7.39 A.M. and run continuously until about 5.45 P.M. On May 6th, before starting the engine the producer was started, and the gas allowed to escape into the air, until the producer was making the gas of the proper quality for use in the engine. The engine was started at 7.44 and run until 5.40 at night. On May 7th, the same method of proceeding was taken as on the day before. The engine was started at 7.26 and run until 5.40 in the evening, great care being taken that the amount of fire in the producer at the end of the test—that is at the end of the third day, should be the same as at the beginning of the test, or on the evening of May 4th, and that the holder should be at the same height as at the beginning of the test.

The tables accompanying this paper are the records of the test as made, and *Fig. 5* graphically represents the tables.

Tables 1*a*, 1*b*, and 1*c* show the total reading of the revolution counter, the revolutions per minute, the total reading of the explosion counter, the explosions per minute, the reading of the pyrometer in degrees F., the gas pressure in inches of water, the gas temperature and the room temperature in degrees F., and the load on the brake in pounds. The total time of running the engine was determined from this table in the following way: The total time of running was made up of two parts, one of which commenced when the explosions had become uniform and the load steady, and to this was added the duration given by dividing the number of explosions before and after the time allowed above, by the average number of explosions per minute during this uniform running.

TABLE I (*a*).—May 5th.

Time.	Revolutions Counter.	Revolutions per Minute.	Explosion Counter.	Explosions per Minute.	Pyrometer.	Gas Pressure. Inches.	Gas Temp. F.	Room Temp. F.	Brake Load. Pounds.
7.39	689,190	—	98,773	—	—	—	—	—	—
7.50	690,890	154"	99,905	109"	490°	1¾	64°6		570°
8.00	692,460	157"	101,124	121·9	690°	1¾	64·7		820°
8.10	694,090	156"	102,413	128·9	685°	1½	65°2		900°
8.20	695,580	156"	103,753	134"	710°	1¾	65°8		980°
8.30	697,140	156"	105,184	143·1	750°	1½	66°8		1140°
8.40	698,690	155"	106,689	150°5	740°	1¾	67°8		1200°
8.50	700,235	154°5	108,166	147·7	745°	1¾	68°		1100°
A.M.									
9.00	701,810	157°5	109,611	149°5	755°	1¾	68°2		1170°
9.10	703,430	162°	111,222	156°2	770°	1¾	68°8		1150°
9.20	705,047	161°7	112,775	155°3	760°	1¾	69°2		1140°
9.30	706,655	160°8	114,321	154°6	775°	1¾	70°		1155°
9.40	708,290	163°5	115,870	154°9	775°	1¾	70°3		1157°
9.50	709,910	162°	117,413	154°3	780°	1¾	70°6		1160°
10.00	711,530	162°	118,958	154°5	770°	1¾	71°3		1145°
10.10	713,155	162°5	120,492	153°4	753°	1¾	71°8		1145°
10.20	714,775	162°	122,031	153°9	755°	1¾	71°4		1150°
10.30	716,400	162°5	123 566	153°5	760°	1¾	72°4		1160°
10.40	718,020	162°	125,104	153°8	760°	1¾	72°6		1160°
10.50	719,640	162°	126,654	155°	755°	1¾	73°		1175°
11.00	721,270	163°	128,161	150°	740°	1¾	74°		1125°
11.10	722,890	162°	129,681	151°	745°	1¾	75°4		1134°
11.20	724,520	163°	131,211	153°	755°	1¾	75°7		1170°
11.30	726,140	162°	132,773	156°2	755°	1¾	76°		1153°
11.50	729,390	162°	135,815	150°4	750°	1¾	77°		1126°
12 P.M.	731,015	162°5	137,393	157°8	760°	1¾	77°4		1169°
12.10	732,635	162°	138,981	158°8	760°	1¾	77°6		1150°
12.20	734,250	161°5	140,571	159°	760°	1¾	77°4		1150°
12.30	735,870	162°	142,141	157°	750°	1¾	77°1		1130°
12.40	737,490	162°	143,738	148°7	720°	1¾	78°2		1075°
12.50	739,125	163°5	145,122	148°4	730°	1¾	78°8		1120°
1.00	740,750	162°5	146,641	151°9	745°	1¾	78°8		1130°
1.10	742,370	162°	148,183	154°2	750°	1¾	79°		1130°
1.20	743 985	161°5	149,737	155°4	760°	1¾	78°3		1155°
1.30	745,610	162°5	15,325	156°8	750°	1¾	79°6		1115°
1.40	747,230	162°	153,841	153°6	745°	1¾	80°		1100°
1.50	748,860	163°	154,365	152°4	745°	1¾	80°		1080°
2.00	750,480	162°	155,881	151°6	745°	1¾	80°2		1135°
2.10	752,090	161°	157,452	157°	740°	1¾	79°		1095°
2.20	753,710	162°	159,021	157°	740°	1¾	78°8		1085°
2.30	755,315	160°5	160,609	157°8	745°	1¾	79°1		1120°
2.40	756,930	161°5	162,176	156°7	750°	1¾	79°3		1115°
2.50	758,540	161°	163,746	157°	750°	1¾	—	81°	1115°
3.00	760,160	162°	165,336	159°	750°	1¾	—	82°	1128°
3.10	761,775	161°5	166,922	158°6	730°	1½	—	82°	1128°
3.20	763,370	159°5	168,513	159°1	—	1½	—		1144°
3.30	765,010	164°	170,143	163°	765°	1½	—		1162°
3.40	766,640	163°	171,771	163°	750°	1¾	—	84°	1106°
3.50	768,295	165°5	173,357	151°7	730°	1¾	—	82°	1150°
4.00	769,950	165°5	174,920	156°3	760°	—	—	84°	1165°
4.10	771,430	164°	176,560	164°	770°	1½	—	85°	1178°
4.20	773,010	158°	178,135	157°5	765°	1¾	—	82°	1200°
4.30	774,580	157°	179,698	156°3	760°	2	—	82°	1203°
4.40	776,190	154°	181,245	153°7	760°	1¾	—	83°	1198°
4.50	777,630	151°	182,750	150°5	760°	1½	—	82°	1192°
5.00	779,190	156°	184,328	158°8	765°	1¾	—	78°2	1198°
5.10	780,695	150°5	185,814	150°6	765°	1½	—	78°7	1193°
5.20	782,220	152°5	187,340	151°6	750°	1¾	—	78°7	1162°
5.30	783,820	160°	188,945	160°	760°	1¾	—	78°6	1175°
5.40	785,430	161°	190,549	160°4	765°	1¾	—	78°	1190°
5.45	786,210	—	191,284	—	—	—	—	—	—
Mean,	—	160°76	—	155°44	752°6	1 11-16	75°5	81°3	1148°5

TABLE I (δ).—May 6th.

Time.	Revolutions. Counter.	Revolutions per Minute.	Explosion Counter.	Explosions per Minute.	Pyrometer.	Gas Pressure. Inches.	Gas Temp. F.	Room Temp. F.	Brake Load. Pounds.
7·44	786,210	—	191,284	—	—	—	—	—	—
7·50	787,130	—	191,783	—	—	—	—	—	—
8.00	788,710	158·	193,308	150·5	—	—	—	—	—
8.10	790,290	158·	194,887	157·9	700·	1¾	68·	—	1084·
8.20	791,890	160·	196,457	157·	730·	1¾	68·	—	1123·
8.30	793,470	158·	198,027	157·	750·	1¾	69·	—	1118·
8.40	795,060	159·	199,615	158·8	760·	1¾	69·5	—	1151·
8.50	996,680	161·	201,185	157·	760·	1¾	70·	—	1160·
9·00	798,300	162·	202,800	161·5	778·	1¾	71·	—	1178·
9.10	799,190	161·	204,400	160·	756·	1¾	70·8	—	1185·
9.20	801,470	156.	206,958	155·8	736·	1¾	71·2	—	1180·
9.30	803,030	156·	207,518	156·	760·	1¾	71·5	—	1190·
9.40	804,630	160·	209,110	159·2	760·	1¾	72·	—	1190·
9.50	806,254	162·4	210,722	161·2	765·	1¾	72·	—	1196·
10.00	807,823	157·2	212,292	157·	770·	1¾	72·	—	1189·
10.10	809,420	159·5	213,880	158·8	760·	1¾	72·	—	1189·
10.20	810,980	156·	215,440	156·	770·	1¾	72·4	—	1190·
10.30	812,580	158·	217,064	160·4	780·	1¾	73·	—	1192·
10.40	814,190	161·	218,673	160·9	775·	1¾	73·4	82·	1181·
10.50	815,810	162·	220,272	159·9	770·	1¾	74·4	—	1168·
11.00	817,425	161·5	221,885	161·3	770·	1¾	74·2	—	1181·
11.10	819,055	161·3	223,491	160·6	770·	2	74·2	—	1179·
11.20	820,605	155·0	225,039	154·8	755·	1¾	74·8	—	1182·
11.30	822,185	158·3	226,619	158·	760·	1¾	76·	82·	1180·
11.40	823,730	154·5	228,163	154·4	765·	2	75·8	—	1180·
11.50	825,235	150·5	229,672	149·9	760·	1¾	76·	—	1183·
12.00	826,755	147·	231,155	147·	760·	2	76·8	86·	1180·
12.10	828,205	150·	232,655	150·	760·	1¾	76·4	84·	1182·
12.20	829,725	152·	234,185	152·	760·	1¾	76·6	—	1174·
12.30	831,350	152·5	235,708	152·3	770·	1¾	76·6	82·	1180·
12.40	832,835	158·5	237,288	158·	765·	1¾	76·2	84·	1190·
12.50	834,400	156·5	238,848	156·	760·	1¾	76·2	82·	1175·
1.00	835,970	157·	240,416	156·8	760·	1¾	76·6	84·	1170·
1.10	837,565	159·5	242,007	159·1	770·	1¾	76·6	84·	1156·
1.20	839,185	162·	243,627	162·	770·	1¾	76·8	—	1160·
1.30	840,815	163·	245,234	161·7	770·	1¾	77·	82·	1165·
1.40	842,445	163·	246,858	162·4	770·	1¾	77·	—	1158·
1.50	844,055	161·	248,740	158·2	755·	1¾	77·6	82·	1179·
2 00	845,605	155·	250,010	157·	760·	1¾	77·2	—	1170·
2.10	847,205	158·	251,590	158·	765·	1¾	77·4	82·	1171·
2.20	848,835	163·	253,220	163·	760·	1¾	77·2	—	1172·
2.30	850,450	161·5	254,815	159·5	765·	1¾	77·3	85·	1174·
2.40	852,070	162·	256,435	162·	770·	1¾	77·	—	1165·
2.50	853,690	162·	258,033	159·8	765·	1¾	77·2	85·	1156·
3.00	855,300	161·	259,980	158·7	760·	1¾	78·	—	1158·
3.10	856,900	160·	261,813	159·3	755·	1¾	77·8	86·	1150·
3.20	858,480	158·	263,738	157·9	760·	1¾	77·8	—	1165·
3.30	860,045	156·5	264,358	156·5	750·	1¾	78·5	87·	1158·
3.40	861,610	156·5	265,920	156·2	750·	1¾	78·	—	1148·
3.50	863,185	157·5	267,490	157·	740·	1¾	78·	88·	1140·
4.00	864,795	161·	269,094	160·4	750·	1¾	78·8	—	1125·
4.10	866,460	166·5	270,494	140·	720·	1¾	79·8	82·	1135·
4.20	868,070	161·	271,944	145·	730·	1¾	77·	80·	1815·
4.30	869,680	161·	273,344	140·	740·	1¾	77·	—	1045·
4.40	871,235	155·	274,894	155·	740·	1¾	77·	—	1138·
4.50	872,830	159·5	276,474	158·	730·	1¾	76·	80·	1137·
5.00	874,435	160·5	278,034	156·	760·	1¾	76·5	82·	1149·
5.10	876,010	158·	279,587	155·3	760·	1¾	77·	—	1149·
5.20	877,590	158·	281,119	153·2	760·	1¾	77·	82·	1170·
5.30	879,180	159·	282,699	158·	760·	1¾	77·2	—	1170·
5.40	880,690	151·	284,614	152·5	—	—	—	—	1200·
Mean.	—	158·73	—	156·73	758·54	1·8	75·13	82·41	1162·5

TABLE I (*c*)—MAY 7TH.

Time.	Revolutions. Counter.	Revolutions per Minute.	Explosion. Counter.	Explosion per Minute.	Pyrometer.	Gas. Pressure. Inches.	Gas Temp. F.	Room Temp. F.	Brake Load. Pounds.
7.26	880,690	—	284,164	—	—	—	—	—	—
7.40	882,900	170·	285,962	134·	640	1½	68·8	64	1030·
7.50	884,505	160·5	287,543	158·1	700	1¼	68·2	—	1051·
8.00	886,145	164·	289,181	163·8	720	1½	70·	72	1051·
8.10	887,785	164·	290,820	163·9	730	1¾	71·	—	1060·
8.20	88,940	161·5	292,424	160·4	740	1¾	71·2	74	1089·
8.30	890,945	154·5	293,964	154·	740	1¾	71·8	—	1139·
8.40	892,490	169·5	295,540	157·6	760	1¾	71·6	71	1154·
8.50	894,108	161·8	297,130	159·	760	1¾	71·6	—	1184·
9·00	895,690	158·2	298,710	158·	750	2	71·9	75	1166·
9·10	897,250	156·	300,267	155·7	750	3	71·9	80	1155·
	Engine	stopped	at 9·11	because	indica	tor	moti	on	strin	g	broke.		
9.30	899,049	—	301,578	—	690	1¾	74·1	82	1119·
9.40	900,475	142·6	302,986	140·8	740	1½	72·8	80	1123·
9.50	902,230	177·5	304,733	174·7	750	1¾	72·5	78	1151·
10.00	903,839	158·9	306,318	158·5	760	1¾	72·2	78	1169·
10.10	905,455	161·6	307,995	160·7	760	1¾	72·2	78	1153·
10.20	907,069	164·4	309,595	160·	760	1¾	72·3	78	1200·
10.30	908,680	161·1	311,136	161·1	770	1¾	72·6	79	1190·
10.40	910,315	163·5	312,785	162·9	760	1¾	72·8	80	1200·
10.50	913,962	163·9	314,378	161·5	750	1¾	73·1	79	1150·
11.10	915,161	159·9	317,569	159·2	740	1¾	73·1	77	1110·
11.20	916,759	159·8	319,160	158·2	750	1¾	73·2	76	1190·
11.30	918,374	161·5	320,774	161·4	760	1¾	73·4	77	1150·
11.40	919,929	155·5	322,329	155·5	750	1¾	73·3	78	1185·
11.50	921,840	155·1	323,859	153·	760	1¾	73·2	78	1165·
12.00	923,148	166·8	325,525	166·6	760	1¾	73·7	77	1140·
12.10	924,668	152·	327,045	152·	760	1¾	74·	77	1183·
12.20	926,278	161·	328,655	161·	764	1¾	74·3	80	1183·
12.30	927,795	147·7	330,132	147·7	764	1¾	74·5	80	1181·
12.40	929,548	179·3	331,924	179·2	758	1¾	74·7	78	1178·
12.50	931,110	156·2	333,485	156·1	745	1¾	74·5	79	1154·5
1.00	932,716	160·6	335,091	160·6	752	1¾	74·4	80	1155·
1.10	934,355	163·9	336,729	163·8	760	1¾	74·4	80	1153·
1.20	935,990	163·5	338,364	163·5	760	1¾	74·6	80	1176·
1.30	937,610	162·	339,974	161·	760	1¾	74·8	77	1190·
1.40	939,155	154·5	341,512	153·8	750	1¾	75·1	78	1160·
1.50	940,740	158·5	343,096	158·4	745	1¾	75·	79	1155·
2·00	942,320	158·	344,676	158·	750	1¾	75·	80	1160·
2.10	943,940	162·	346,296	162·	760	—	75·	81	1140·
2.20	945,600	166·	347,948	165·2	750	1¾	75·	80	1130·
2.30	947,300	160·	349,546	159·8	755	1¾	74·8	78	1160·
2.40	948,860	166·	351,196	165·	752	1¾	74·8	82	1100·
2.50	950,536	167·2	352,864	165·8	740	1¾	74·9	78	1113·
3.00	952,193	165·5	354,504	164·	750	1¾	75·	80	1142·
3.10	953,831	163·8	356,141	163·7	752	1¾	75	80	1163·
3.20	955,487	165·6	357,792	165·1	754	1¾	75·	80	1175·
3.30	957,120	162·2	359,412	162·	736	1¾	75·1	80	1117·
3.40	958,680	157·1	360,980	156·8	720	1¾	75·1	80	1119·
3.50	960,397	171·7	362,696	171·6	727	1¾	75·2	78	1127·
4.00	961,930	153·3	364,225	152·9	740	2	75·3	78	1129·
4.10	963,700	177·	365,989	176·4	740	2	75·	80	1143·
4.20	965,340	164·	367,625	163·6	742	2	75·1	78	1144·
4.30	966,784	160·4	369,064	159·9	740	2	75·2	80	1154·5
4.40	968,371	158·7	370,650	158·6	740	2	75·2	78	1158·
4.50	969,938	156·7	372,216	156·6	730	2	75·4	78	1169·
5.00	971,512	157·4	373,790	157·4	748	1¾	75·3	78	1176·
5.10	973,125	161·3	375,402	161·2	747	1¾	75·4	79	1162·
5.20	974,657	153·2	376,929	153·7	744	1¾	75·6	78	1068·
5.30	976,238	158·1	378,507	157·8	721	1¾	—	78	1159·5
5.40	977,836	159·8	380,104	159·7	735	1¾	—	—	1155·
Mean,	—	160·9	—	160·43	747·3	1¾	73·4	80·2	1138·3

Thus, on May 5th, the average explosions per minute, from 9 A.M. to 5.40 P.M., was 155·55. The number of explosions before 9 A.M. and after 5·40 P.M. amounted to 11,623, which was the equivalent of 74.73 minutes at the average above found, so that the total running time for that day is taken as 9 hours 54·73 minutes. On May 6th, from 8 A.M. to 5·10 P.M. was taken as the time from which to determine the average number of explosions per minute, and the total time for this day was 9 hours 49·96 minutes. On May 7th, as the engine was stopped during the test for the purpose of securing the indicator string, the total time amounted to 10 hours and 4 minutes, and the total time of running for the three days amounted to 1788·69 minutes, with an average number of explosions 157·57.

From this table was also worked out the brake horse-power. The prony brake was arranged with a weight on the north side and another weight on the south side, the weight on the north side resting on a platform scale and being so arranged that the pressure brought by the friction of the brake was downward on the scales. The weight on the north side averaged 628 pounds, while the weight on the south side averaged 469 pounds. The circumference of the pulley was 15 feet 3 inches, and the distance from the pulley where the circumference was measured to the knife edge to which the north weight was attached was $7\frac{3}{4}$ inches, and the distance from the pulley to the knife edge to which the south weight was attached was $7\frac{1}{2}$ inches, or of the lever arm of the south weight was 3·072 feet, and of the north weight was 3·073 feet, and the brake horse-power was determined from the following formulæ:

$$\text{B.H.P.} = \frac{6{\cdot}2832\,N\,(3{\cdot}073\,w - [3{\cdot}073 \times 628 - 3{\cdot}052 \times 469])}{33{,}000}$$

N being the number of revolutions per minute;
w, the load on the scales in pounds.

The average brake horse-power for the first day, May 5th, was 92·73; for the second day, May 6th, was 92·85, and for the third day, May 7th, was 91·82, the average for the entire time was 92·49.

For the entire running time, the average number of explosions per minute was 157·57. The average number of revolutions was 160,145. The average reading of the pyrometer was 752·81. The average pressure of the gas was ·062 pounds, the barometer being 14·686 pounds. The average temperature of the gas was 74·°68 F.

Table II gives the indicated horse-power for each of the cards as taken during the time of the test, and it will be noted that only those cards were put down that were taken during the time the engine was supposed to be running under uniform conditions. Indicators were fitted to both the lower and the upper cylinders, with springs in them which were good to over 300 pounds. During the preliminary tests which were made on the 3d and 4th of May, it was found that these indicators would not do the work, either the springs or the pencil bar being broken from the violence of the explosion. After repairing them, the same results occurred again, and we were obliged to use a Thompson indicator with a one-quarter square inch piston which had been in use in the works for a considerable time. It was found that if the indicator was allowed to remain on the engine between the time of taking successive cards, the heat conducted from the cylinder was sufficient to melt the solder holding the spring to the screw ends, but after the test was commenced, the indicators were removed after taking each card and there was practically no difficulty in this way. The indicator piston was not at all tight, or if reasonably tight at the beginning of the test was not so at the end. After the test the indicator was put on a steam boiler and the spring calibrated; as there was considerable leakage past the piston, a mercury column was attached to the upper side of the piston, and allowance made for this pressure in determining the scale, which was found to be practically 190 pounds to the inch. It will thus be seen that there is not a very large amount of confidence to be placed in the indicated horse-power, although the results are probably fairly correct.

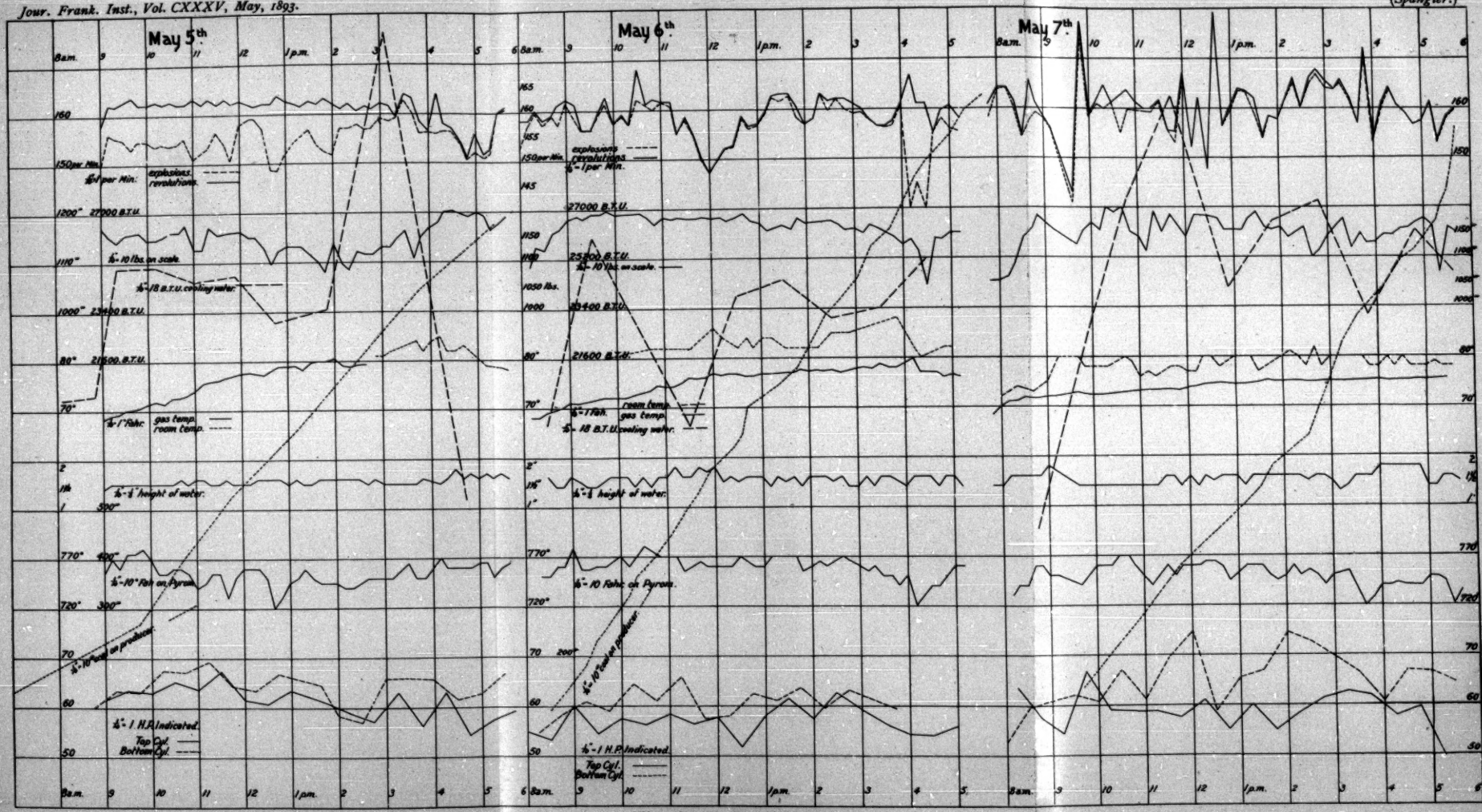


Fig. 5.—Record of Tests.

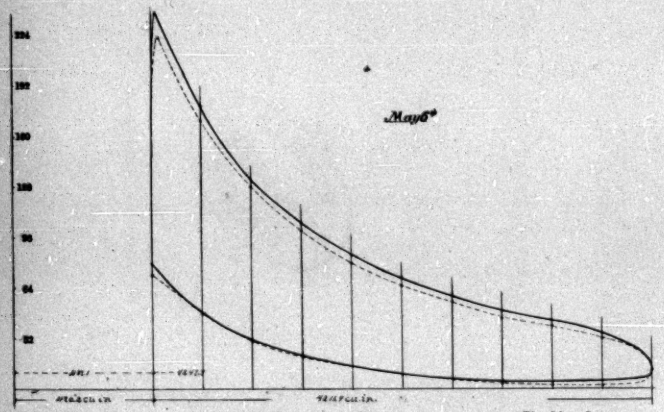


Fig. 6.—Average Indicator Card for each Cylinder during May 6.

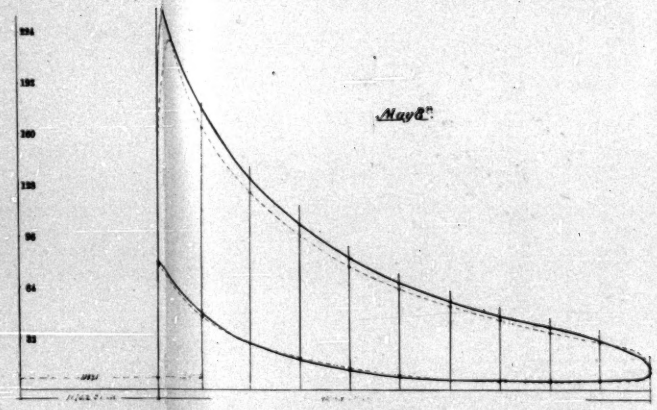


Fig. 8.—Average Indicator Card for each Cylinder during May 8.

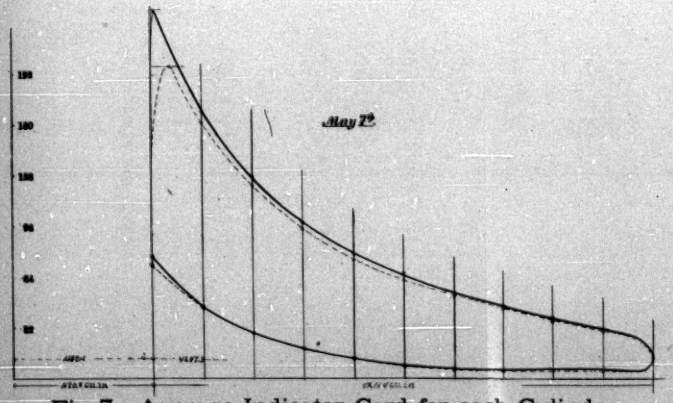


Fig. 7.—Average Indicator Card for each Cylinder during May 7.

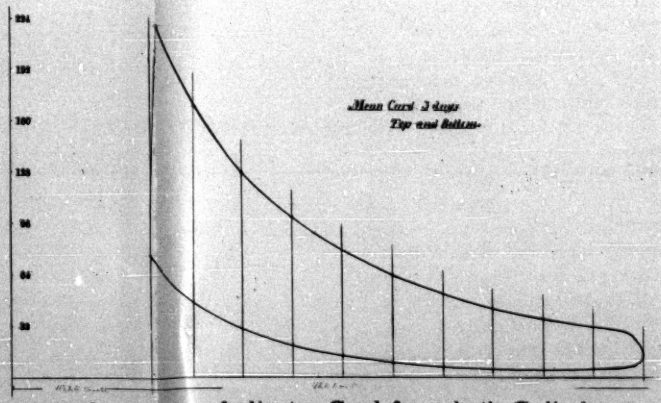


Fig. 9.—Average Indicator Card from both Cylinders during May 6, 7, and 8, 1892.

TABLE II (*a*)—MAY 5TH.—*Indicated Horse-power.*

Top Cylinder.			Bottom Cylinder.		
Card.	Time.	I.H.P.	Card.	Time.	I.H P.
11	9.00	64·86	10	8.45	62·37
13	9.30	66·78	12	9.15	66·20
15	10.00	66·26	14	9.45	65·78
17	10.30	68·78	16	10.15	70·58
19	11.00	66·84	18	10.45	70·16
21	11.30	70·88	20	11.15	72·22
23	12.00	64·86	22	11.45	67·09
25	12.30	63·92	24	12.15	66·16
27	1.00	66·73	26	12.45	69·71
29	1.45	64·19	28	1.38	67·09
31	2.15	61·98	30	2.00	60 69
33	2.45	60·27	32	2.30	57·45
35	3.15	66·21	34	3.00	68·44
37	3.45	59·75	36	3.30	68·65
39	4.15	66·51	38	4.00	68·40
41	4.45	57·13	40	4.30	64·15
43	5.15	60·26	42	5·00	65·34
45	5.42	62·17	44	5.30	67·26
Mean, ...	—	64·36	—	—	66·80

Total I H. P., ... 131·15
Mean brake horse-power, ... 92·73

TABLE II (*b*)—MAY 6TH.—*Indicated Horse-power.*

Top Cylinder.			Bottom Cylinder.		
Card.	Time.	I.H.P.	Card.	Time.	I.H.P.
46	8.05	57·62	47	8.15	56·95
48	8.30	55·86	49	8.45	60·88
50	9.00	63·23	51	9.15	63·31
52	9.30	57·20	53	9.49	61·48
54	10.00	60·49	55	10.15	67·02
56	10.30	59·14	57	10.45	63·76
58	11.00	61·47	59	11.15	68·49
60	11.30	59·31	61	11.45	59·84
62	12.00	60·84	63	12.15	60·41
64	12.30	60·86	65	12.45	65·04
66	12.57	61·20	67	1.15	63·75
68	1.30	64·58	69	1.45	66·45
70	2.00	60·54	71	2.15	62·13
72	2.30	65·92	73	2.45	65·80
74	3.00	62·28	75	3.15	63·77
76	3.30	59·96	77	3.45	61·87
78	4.00	57·04	—	—	—
79	4.30	56·70	—	—	—
80	5.00	58·73	—	—	—
Mean, ...	—	59·81	—	—	63·08

Total I.H.P., ... 122·89
Mean brake horse-power, ... 92·85

TABLE II (c)—MAY 7TH.—*Indicated Horse-power.*

Top Cylinder.			Bottom Cylinder.		
Card.	Time.	I.H.P.	Card.	Time.	I.H.P.
81	7.45	44·28	82	8 00	54·43
83	8.15	66·59	84	8.35	62·23
85	8.47	60·54	86	9.00	Indicator string broke.
87	9.05	57·08	88	9.30	64·72
89	9.45	70·10	90	10.00	63·32
91	10.15	69·19	92	10.30	69·73
93	10.45	61·89	94	11.01	63·56
95	11.15	61·86	96	11.30	72·38
97	11.45	60·60	98	12.00	77·90
99	12.15	65·14	100	12.30	61·30
101	12.45	58·00	102	1.00	68·20
103	1.15	63·26	104	1.30	69·71
105	1.45	57·64	106	2.00	77·68
107	2.22	61·25	108	2.30	75·79
109	2.45	64·42	110	3.00	72·58
111	3.15	65·92	112	3.30	69·27
113	3.45	64·17	114	4.00	63·25
115	4.15	60·92	116	4.30	69·84
117	4.45	62·58	118	5.00	69·77
119	5.15	59·26	120	5.30	67·41
Mean, ...	—	61·10	—	—	67·96

Total I.H.P., ... 129·06
Mean brake horse-power, ... 91·82

Figs. 6, *7*, *8* and *9* are the average of all the indicator cards taken. *Fig. 6* shows the average of the cards from both cylinders taken on May 5th, and *Figs. 6* and *7* for May 7th and 8th. *Fig. 9* is the average for all the cards taken. It will be noted that the average cards from the bottom cylinder are invariably larger than those from the top cylinder and an examination of Table VIII shows that the amount of air supplied to the bottom cylinder was more nearly the amount required for complete combustion than that supplied to the top one.

The size of the cylinder was practically 14⅛ inches diameter by 25-inch stroke. After the test the cylinder and the clearance spaces were filled with water.

Table III shows the volume of both cylinders, together with the clearances. The displacement of the bottom cylinder was found to be 4211·36 cubic inches and the clearance 1170·19, or 27·98 per cent. The displacement of the top cylinder was found to be 4247·94 cubic inches, and the clearance 1187·09 cubic inches, or 27·94 per cent. The volume as found from filling the cylinder with water, was used in determining the horse-power.

TABLE III.—*Clearance Determination.*

TEMPERATURE OF WATER, 61° TO 62° F.

No.	Before.	After.	Net.	Volume.
		Bottom Valve.		
1	27·56	21·62	5·94	164·5974 cubic inches.
		Top Valve.		
2	24·17	18·33	5·84	161·8864 cubic inches.
		Top Cylinder Clearance.		
2	26·07	8·78	17·29	(38·58 — 1·58)
3	27·09	8·79	18·30	× 27·71 = 1025·27 cubic inches.
4	28·63	25·66	2·97	
			38·58	
		Top Cylinder Displacement.		
1	29·65	8·81	20·84	
2	27·62	8·77	18·85	
3	27·97	8·77	19·20	
4	25·66	8·80	16·86	153·3 × 27·71 = 4247·943 cubic inches.
1	27·92	8·83	19·09	
2	28·50	8·78	19·72	
3	28·65	8·80	19·85	
4	29·98	11·09	18·89	
	225·95	72·65	153·30	
		Filling Pipe.		
—	18·32	16·74	1·58	
		Bottom Cylinder Clearance.		
1	30·34	8·82	21·52	(37·87 — 1·58) × 27·71 = 1005·5959 cubic inches.
2	29·95	13·60	16·35	
	60·29	22·42	37·87	
		Bottom Cylinder Displacement.		
3	26·64	10·37	16·27	
4	27·57	10·91	16·66	
1	26·33	9·31	17·02	
2	27·52	9·30	18·22	
3	27·23	9·10	18·13	151·98 × 27·71 = 4211·3658 cubic inches.
4	26·96	9·23	17·73	
1	27·65	9·42	18·23	
2	27·61	9·45	18·16	
3	27·13	15·57	11·56	
	244·64	92·66	151·98	

Total clearance top cylinder, ... 1187·0946 cubic inches, 27·94 per cent.
Total clearance bottom cylinder, ... 1170·1933 cubic inches, 27,978 per cent.

TABLE IV (*a*)—MAY 5TH.—*Jacket Water.*

Time.	Weight Water.	Temp. Disc.	Temp. Inlet.	Pounds C.	B.T.U.
		°C.	°C.		
8.05	664	37·33	26·91	13,280	5976·
8.50	611	46·58	28·83	10,845	4880·25
9.22	645	53·75	32·5	13,775	5171·75
10.10	678	55·5	33·	13,900	6255·
10.58	680	56·	36·	13,600	6120·
11.54	680	57·66	36·5	13,710	6169·5
12.45	687	56·33	37·75	12,768	5746·2
1.52	686	57·25	38·25	13,034	5865·3
3.06	673	60·00	39·33	18,642	83889
4.43	700	40·00	23·66	11,666	5250·

TABLE IV (*b*)—MAY 6TH.—*Jacket Water.*

Time.	Weight Water.	Temp. Disc.	Temp. Inlet.	Pounds C.	B.T.U.
		°C.	°C.		
8.25	664	46·66	30·	10,760	4843·
9.25	801	39·	21·	14,418	6488·
10.25	427	59·	29 66	12,518	5633·
11.25	531	64·	34·	10,620	4779·
12.25	631	57·	36·	13,261	5967·
1.25	698	56·33	36·92	13,551	6098·
2.25	594	59·33	34·92	12,987	5758·
3.25	520	63·	38·	13,000	5850·
4.25	691	56·66	37·13	13,941	6273·
5.25	697	57·5	38·	12,894	5802·

TABLE IV (*c*)—MAY 7TH.—*Jacket Water.*

Time.	Weight Water.	Temp. Disc.	Temp. Inlet.	Pounds C.	B.T.U.
		°C.	°C.		
8.50	521	50·33	32·	9,550	4297·
9.50	700	49·66	32·	12,361	5562·
10.50	703	54·5	33·	15,116	6802·
11.50	703	53·83	34·33	13,739	6178·
12.50	701	53·00	34·	13,380	6021·
1.50	532	61·66	34·	14,715	6622·
2.50	769	41·66	22·	15,119	6803·
3.50	694	50·5	32·	12,839	5817·
4.50	519	61·	33·	14,529	6538·
5.35	696	52·	33·83	13,347	6006·

Mean B.T.U., May 5th, 5904·9. May 6th, 5742·5. May 7th, 6218·1.

Table IV, *a*, *b* and *c*, shows the records of the water used in the jacket. The first column gives the time when the water began to fill the tanks. The second column gives the weight of water in pounds that flowed into the tank in four minutes. The third and fourth columns give the temperatures of the inflowing and discharge water in degrees C., each number being the mean of three readings. The fifth column gives the result in pound degrees found by multi-

plying the temperature change by the pounds discharged, and the sixth column gives the number of British thermal units carried away per minute, being nine-twentieths of the fifth column.

Table V gives the quantity of coal that was used each day of the test, amounting to 1069·6 pounds on May 5th, 1324·2 on May 6th, 1263·6 on May 7th, a total of 3157·4 pounds for the entire time.

TABLE V.—*Coal.*

Time.	Weight.	Time.	Weight.	Time.	Weight.
May 5th.		10.40	29·5	*May 7th.*	
A.M.		11.06	50·6	A.M.	
7·00	129·8	11.25	48·4	8.05	134·4
9.45	136·3	11.40	33·0	10·00	118·4
10.40	127·6	11.55	54·6	11.00	127·2
11.44	131·	P.M.		P.M.	
P.M.		12.20	48·7	1.00	125·1
1.15	140·3	12.35	27·2	1.30	32·7
2.30	139·3	12.40	53·5	1.45	51·2
3.45	135·2	1.23	42·	2.13	28·8
5.22	130·1	1.48	34·1	2.32	22·3
		2.05	36·2	2.47	59·1
Total, . . 5·5 =	1069·6	2.23	49·	3.01	61·3
		2.39	32·3	3.15	65·6
May 6th.		3.03	45·2	3.35	55·1
A.M.		3.24	54·8	4.05	54·6
7.38	42·7	3.43	34·0	4.30	59·
8.28	47·5	4.00	49·8	4.51	30·7
8.56	40·2	4.15	50·	5.18	59·
9.15	49·	4.30	34·	5.22	31·1
9.26	50·1	5.00	50·4	5.30	28·5
9.48	34·1	5.19	49·7	5.35	54·4
10.09	54·7	5.40	30·	5.40	75·1
10.20	48·9	Total, . . 5·6 =	1324·2	Total, . . 5·7 =	1263·6

Table VI shows in the first column the time at which the sample of gas was taken. The apparatus used was the Elliott, in which the readings before the explosions indicate the differences between 100 cubic centimetres and the quantity of gas in the apparatus. In the explosion tube the numbers represent the total volume used. The second column in the table indicates the reading of the original gas. The third column, headed KOH, is the reading after potassic hydrate has been added, and the difference between that column and the one preceding is the amount of CO_2 which was present in the gas. The fourth column represents the reading after the oxygen has been removed; the fifth column the reading after the carbonic oxide has been removed. The sixth column represents the quantity of the

remaining gas that was taken for explosion. The next column represents the quantity of gas after a certain proportion of air has been added, and the difference between the last two columns is the quantity of air added. The next column represents the quantity of gas after the mixture has been exploded, the hydrogen having disappeared. The last column is the quantity of gas after the carbonic acid has been taken out, and practically represents nitrogen. The remaining columns represent the number of cubic centimetres of the different constituents of the original gas.

TABLE VI.—*Gas Analyses.*

Time.	Readings.				Cubic Centimetres.											
	Orig. Vol.	KOH.	Pyro.	$CuCl_2$.	Before exp.	Air Added.	After exp.	KOH.	Gas.	CO_2.	O.	CO.	Rem.	Before exp.	Contraction.	CO_2.
May 5th.																
8.55	11·2	14·2	14·2	36·1	12·2	95·2	—	—	—	—	—	—	—	—	—	—
9.27	4·3	6·9	6·9	24·5	16·7	38·2	—	—	—	—	—	—	—	—	—	—
11.10	4·	6·3	6·3	29·6	22·3	48·	44·5	44·3	96·	2·3	0	23·3	70·3	22·3	3·5	·2
2.05	8·5	12·6	20·7	36·5	11·	25·4	—	—	—	—	—	—	—	—	—	—
4.34	·8	4·9	5·1	22·5	16·2	42·4	39·5	38·8	99·2	4·1	·2	17·4	77·5	16·2	2·9	·7
May 6th.																
8.04	5·9	10·1	10 1	36·1	15·6	36·	—	—	—	—	—	—	—	—	—	—
9.02	4·1	6·1	6·2	36·1	11·	20·5	—	—	—	—	—	—	—	—	—	—
11.25	5·5	7·5	7·5	35·9	21·5	28·7	25·3	24·5	94·5	2·	—	28·4	64·1	21·5	3·2	1·
1.41	11·5	14·9	14·9	39·8	24·8	33·2	29·9	—	88·5	3·4	—	24·9	60·2	24·8	3·3	·1
3.15	10·8	14·3	14·8	39·7	24·2	33·1	30·	—	89·2	3·5	·5	24·9	60·3	24·2	3·1	·5
May 7th.																
7.00	10·2	14·5	14·5	38·7	—	—	—	—	89·8	4·3	—	24·2	—	—	—	—
8.25	10·4	13·3	13·3	39·5	32·	45·2	40·	39·	89·6	2·9	—	26·2	60·5	32·	5·2	·2
10.45	7·4	10·4	10·4	36·2	43·1	56·7	51·3	—	92·6	3·	—	25·8	63·8	43·1	5·4	—
2.03	10·4	15·4	15·8	38·8	37·3	50·2	44·4	43·8	89·6	3·	—	23·	61·2	37·3	5·8	·6
3.55	6·4	12·7	13·3	34·8	47·7	61·6	58·	57·5	93·6	6·9	—	21·5	65·2	47·7	3·6	·5

The work is continued beyond this in only those cases in which the readings were completed. The other cases are here given to show that those used were about mean values.

Table VII is a continuation of those portions of Table VI, in which a complete analysis was made, and reduces the gas into its percentage by volume.

Table VIII gives the analysis of the top and bottom exhausts, the headings of the columns sufficiently explaining the quantities entered. The Elliott apparatus was used

on part of the work, and on the balance the readings beginning at 100 or 72 being the latter.

TABLE VII.—*Gas Analyses continued.*

	Per Cent. Vol.					
	CO_2	O	CO	H	CH_4	N
May 5th.						
11.10	2·40	—	24·27	7·46	·66	65·21
4.34	4·13	·20	17·54	4·78	3·40	69·95
May 6th.						
11.25	2·72	—	30·05	2·58	3·16	62·09
3.15	3 92	·56	27·92	3·91	1·40	62·29
May 7th.						
8.25	3·73	—	29·24	4·51	2·10	60·92
2.03	5·38	·45	25·65	5·60	1·10	61·62
3.55	6·73	·64	22·97	2·72	·73	66·22
	4·02	·26	25·38	4·51	1·79	64·04 = 100

	% Vol.			% Wt	*Weight in 100 Pounds Gas.* C	O	H	N
CO_2	4·02 × 22	=	88·41	= 6·50	1·77	4·73	—	—
O_2	·26 × 16	=	3·16	= ·23	—	·23	—	—
CO	25·38 × 14	=	355·32	= 26·08	11·18	14·90	—	—
H	4·51 × 1	=	4·51	= ·33	—	—	·33	—
CH_4	1·79 × 8	=	14·32	= 1·05	·79	—	·26	—
N	64·04 × 14	=	896·56	= 65·81	—	—	—	65·81
			1362·31	100·00	13·74	19·86	·59	65·81

Table IX gives on the left-hand side the average composition by weight and volume of the exhaust gas, and on the right-hand the composition of enough of the gas by weight to include 13·74 per cent. of carbon and ·59 per cent. of hydrogen, which was the amount in 100 parts of the original gas; that is, each 100 parts of the original gas required 126·64 parts of air by weight, making 226·64 pounds of exhaust gas. The oxygen and nitrogen added, are in the proportion of 22·5 : 77·5, which is about the proportion they should have had in the air added.

Table X shows the variation in condition of the fire during the time of the test; the first column showing the time at which the reading was taken; the second the distance

from the bottom of the rod to the bottom of the fire; the third the distance from the bottom of the rod to the top of the fire, and the fourth the thickness of the fire. The gas meter was attached to the pipe leading to the second scrubber, as shown in *Fig. 3*, by means of which the attendant noted the condition of the gas. The total quantity of gas used in this meter was 2,530 cubic feet. The power necessary to run the blower was found to be ·085 horse-power on one inch of water, ·28 for 6½ inches of water and ·431 for 9½ inches of water.

TABLE VIII.—*Exhaust Analyses.*

Time.	Readings.				Volumes.				Per Cent. Volumes.				
	Orig. Vol.	KOH	Pyro.	Cu_2Cl_2	Gas.	CO_2	O	CO	Gas.	CO_2	O	CO	N
Top Exhaust													
May 5th.													
10.20	3°	16·4	19·7	22·7	97°	13·4	3·3	3°	100	13·6	3·4	3·1	
5.15	1·6	17·1	19·1	18·7	98·4	15·5	2°	—	100	15·7	2·1	—	
May 6th.													
10.55	7°	20·5	23°	23°	93°	13·5	2·5	—	100	14·5	2·6	—	
2.55	100°	84·8	81·6	100°	15·4	3°	—	—	100	15·4	3°	—	
4.47	72°	19·9	24·4	92·8	12·2	4·8	—	—	100	13·1	5·2	—	
May 7th.													
9.10	100°	84·8	81°	81°	100°	15·2	3·8	—	100	15·2	3·8	—	
10.15	9·8	21·9	24·8	24·8	90·2	19·1	2·9	—	100	13·4	3·2	—	
11.45	9·3	23·8	25·5	25·5	90·7	14·5	1·7	—	100	15·9	1·8	—	
1.20	12·4	25·1	28·7	87·6	12·7	3·6	—	—	100	14·5	4·2	—	
2.55	12°	25·5	28·2	88°	13·5	2·7	—	—	100	15·3	3·1	—	
5.30	10·2	24°	27·8	27·7	89·8	13·8	3·8	—	100	15·4	4·1	—	
Bottom Exhaust.													
May 5th.													
11.35	4·5	19·5	20·1	27°	95·5	15°	6·6	—	100	13·7	9·0	—	
12.25	2.1	17·3	20·1	16·2	97·9	15·2	2·8	—	100	15·5	2·9	—	
4.00	8·1	21·3	22°	21·7	91·9	13·1	1°	—	100	14·2	1·1	—	
May 6th.													
10.55	100°	83·2	83·2	82·7	100°	16·8	—	·5	100	16·8	—	·5	
1 08	10·4	25·1	26·0	26·2	89·6	14·7	·9	·2	100	17·5	1·0	·2	
2.55	4·6	21·0	21·7	22·9	95·4	17·4	·7	1·2	100	18·2	·7	1·2	
May 7th.													
9.10	9·9	25°	26·4	26·4	90·1	15·1	1·4	—	100	16·7	1·5	—	
11.45	100°	82·8	81·6	82·2	100°	17·2	1·2	·6	100	17·2	1·2	·6	
12.30	9°	23·3	24·5	24·5	91°	14·3	1·2	—	100	15·7	1·4	—	
3.25	11·3	25·7	26·5	26·5	88·7	14·7	·8	—	100	16·6	·1	—	
4.47	100°	82°	82°	82°	100°	18°	—	—	100	18°	—	—	
4.55	3·8	18·6	22·7	22°	96·2	14·8	4·1	—	100	15·4	4·2	—	
Mean of top and bottom,									100	15·60	2·24	·23	81·93

TABLE IX.—*Weight of Exhaust Gas Corresponding to One Hundred Pounds of Producer Gas*

	Per Cent. Volume.	Per Cent. Weight.	Weight in 100 Pounds Gas.			Weight Corresponding to 100 Pounds Original Gas, or 13·74 C + ·59 H.			
			C	O	N	C	O	N	H
CO_2, ...	15·60	22·44	6·12	16·32	—	13·54	36·11	—	—
O_2, ...	2·24	2·34	—	2·34	—	—	5·18	—	—
CO, ...	·23	·22	·09	·13	—	.20	·29	—	—
N, ...	81·93	75·00	—	95·00	95·00	—	—	165·94	—
	100·00	100·00	6·20	18·79	75·00	—	—	—	—
					5·38 H_2O	—	4·79	—	·59
From 100 pounds original gas we have = 226·64 exhaust =						13·74	46·37	165·94	·59

TABLE X.—*Height of Fire and Ash in Producer.*

Time.		Depth of Fire.		
May 4th.		*inches.*	*inches.*	*inches.*
5.45 P.M.	Bottom of rod to top of ashes, .	14¼	39¾	25'
May 5th.				
6.50 A.M.	. . . . .	14'	34½	20½
8.35	. . . . .	—	—	Fire raked.
10.00	. . . . .	—	—	Fire raked.
10.07	. . . . .	12'	32'	20'
1.55 P.M.	. . . . .	—	—	Fire raked.
2.00	. . . . .	18'	30'	12'
5.00	. . . . .	19'5	40'	20'5
6.00	. . . . .	19'	40'	21'
May 6th.				
7.30 A.M.	. . . . .	13'5	24'	10'5
10.30	. . . . .	18'	32'	14'
12.40 P.M.	. . . . .	19'	43'	24'
4.30	. . . . .	20'	41'	21'
5.40	. . . . .	22'	41'5	19'5
May 7th.				
7.15 A.M.	(*Note*—Blast was on 15 minutes.)	20'	25'	5'
11.00	. . . . .	18'5	37'	18'5
12.30 P.M.	. . . . .	20'	41'	21'
1.30	. . . . .	18'	38'	20'
2.30	. . . . .	20'	38'	18'
3.30	. . . . .	12'5	36'5	24'
4.30	. . . . .	18'	42'	24'
5.30	. . . . .	18'	43'	25'
8.50	. . . . .	18'	44'	26'

At the end the distance from the top of producer to top of fire was 3 feet 6 inches.

GAS METER—CONNECTED TO BURNER.

	Cubic Feet.
May 5th, 7 A.M.,	500
6th, 7 A.M.,	1,340
7th, 7	2,190
7th, 6 P.M.,	3,030
Total	2,530
Average . . . . . 84·8 cubic feet per hour.	

The following will give the calculations to determine the efficiency of the plant and the different portions of it, together with the amount of coal used per horse-power:

Total coal used, ... = 3657·4 pounds.
Time, ... = 1788·69 minutes.
Explosions per minute, ... = 157·57
Total carbon, $3657{\cdot}4 \times \frac{84{\cdot}76}{100}$ . . . . . = 3100·01 pounds.
Gas used in meter, ... = 2,530 cubic feet.

Comp. of gas by vol. and wt. =

Volume.		*Weight.*	
CO_2, 4·02		6·5	
O, ·26		·23	
CO, 25·38	C = 15·60	26·08	total C = 13·74
H, 4·51		·33	
CH_4, 1·79		1·05	
N, 64·04		65·81	

Mean barometer 29·90 in. mercury, ... = 14·686 pounds.
Meter pressure, gas, ... = ·062 pounds.
Temperature gas, ... = 74°·68 F.
Total absolute pressure gas, ... = 14·748 pounds.

Weight of carbon in one cubic foot of gas at 14·748 pounds, 74°·68 F.

$$= {\cdot}071128 \times \frac{14{\cdot}748}{14{\cdot}7} \times \frac{492{\cdot}66}{535{\cdot}34} \times {\cdot}1560 = {\cdot}0102446 \text{ pounds.}$$

[Haswell, p. 218.]

Total carbon weight used in meter = ·0102446 × 2,530 = 25·92 pounds.
Carbon chargeable to engine = 3100·01 — 25·92 = 3074·09 pounds.

Coal used for engine

$$= \frac{3074{\cdot}09}{{\cdot}8476} = 3{,}626 \text{ pounds.}$$

Per Cent.

Composition of coal,
4·20 moisture,
6·88 volatile and combustion { Total carbon 84·76 per cent. or approximately { 5·10 C_2H_4 / 1·78 H
80·41 fixed C.
8·51 ash.

Heat obtainable from one pound of coal (containing ·8476 pounds carbon).

·0580 CH_4	× 23,883	= 1385·214
·0173 H	× 62,032	= 1073·154
·8041 C	× 14,500 [Wilson, p. 251.]	= 11659·450
Total		14117·818 B.T.U.

COMPOSITION OF GAS IN PRODUCER CONTAINING ·8476 POUNDS C.

	Per Cent. Weight.		
CO_2	= 6·5		·404
O	= ·23		·014
CO	= 26·08	× ·8476 / 13·74 =	1·609
H	= ·33		·020
CH_4	= 1·05		·065
N	= 65·81		4·060
	100·		6·172

CO_2	·404	
O	·014	[Wilson]
CO	1·609 × 4,328	= 6963·75
H	·020 × 62,032	= 1240·64
CH_4	·065 × 23,883	= 1552·40
N	4·060	—

Heat in producer gas per pound coal, ... 9756·79 B.T.U.

Amount of carbon per explosion approximately

$$= \frac{\text{total C received}}{\text{exp.} \times \text{time}} = \frac{3074{\cdot}09}{157{\cdot}57 \times 1788{\cdot}69} = {\cdot}010907$$

Gas per explosion

$$= \frac{100}{13{\cdot}74} \times {\cdot}010907 = {\cdot}07938$$

Air per explosion

$$\frac{126{\cdot}64}{13{\cdot}74} \times {\cdot}010907 = {\cdot}09963$$

TO DETERMINE WEIGHT OF 1 CUBIC FOOT GAS AT 14·748 POUNDS, 74°·68 F.

Moisture in gas, pressure ·8579 inch mercury = ·4214 pounds per square inch. [Stewart, p. 491.]

Pressure of dry gas = 14·3166 pounds temperature, 74°·68 F.

1 cubic foot H at 14·7 pounds, 32° F. = ·005594 pound. [Haswell, p. 218.]

1 cubic foot H at 14·3166 and 74°·68 weighs

$$·005594 \times \frac{14·316}{14·7} \times \frac{492·66}{535·34} = ·0050133$$

1 cubic foot of gas weighs

CO_2, ...	4·02	× 22 =	88·44
O, ...	·26	× 16 =	4·16
CO, ...	25·38	× 14 =	355·32
H, ...	4·51	× 1 =	4·51
CH_4, ...	1·79	× 8 =	14·32
N, ...	64·04	× 14 =	896·56

1363·31; sp. grav. (H = 1) = 13·6331

Weight 1 cubic foot gas = ·0050133 × 13·6331 = ·06835 pounds.

Cubic feet gas used per explosion

$$= \frac{·07938}{·06835} = 1·1614 \text{ cubic feet} = 2006·90 \text{ cubic inches.}$$

Cubic feet occupied by air per explosion. Assuming that the composition of the air is 23 parts O and 77 parts N, its specific gravity is 14·46 as compared to H, and

1 cubic foot air = ·0050133 × 14·46 = ·72492 pounds.

Cubic feet of air used

$$= \frac{·09963}{·07249} = 1·3744 \text{ cubic feet} = 2374·96 \text{ cubic inches.}$$

Or the total volume of gas and air fed to the cylinder per explosion equals 2374·96 + 2006·90 = 4381·86 cubic inches.

As this charges all coal to engine, including leakage and that used for blowing off in the morning, this amount should be greater than that required to fill the cylinder at atmospheric pressure.

From cards the average volume filled at atmospheric pressure was approximately 4012·673 cubic inches.

WEIGHT OF MOISTURE IN GAS AND PER EXPLOSION.

Cubic inches, ...	= 2006·9 = 1·1614 cubic feet.
Pressure, ...	= ·4214 pounds per square inch.
Temperature, ...	= 74°·68 F. = 23°·71 C.
One cubic metre, ...	= 21·18 gramme [Kohlrausch, p. 229.]

$$35·3161 \text{ cubic feet} = \frac{21·18}{2·205 \times 1{,}000} \text{ pounds.}$$

$$1·1614 \text{ cubic feet} = \frac{21·18 \times 1·1614}{2·205 \times 35·3161} \text{ pounds} = ·0003159 \text{ pounds.}$$

ENTERED CYLINDER PER EXPLOSION.

	Weight.		*Pounds Gas.*		*Heat Units.*
CO_2,	6·50		·005159700		
O,	0·23		·000182574		
CO,	26 08		·020702304	× 4,328 =	89·60
H,	·33		·000261954	× 62,032 =	16·25
CH_4,	1·05		·000833490	× 23,883 =	19·91
N,	65·81		·052239978		
	100·00	× ·07938/100 =	·07938		

Moisture,	·0003159	
Air, 126·64 × ·07938/100 =	·100526832	
Total weight per explosion,	·180222732	
Total heat per explosion,		125·76

DISCHARGED FROM CYLINDER PER EXPLOSION.

	Weight.		*Pounds Gas.*		
CO_2,	49·65		·039412170		
O,	5·18		·004111884		
CO,	·49		·000388962	× ·4328 =	1·68
H_2O,	5·38		·004270644		
N,	165·94		·131723172		
	226·64	× ·07938/100 =			

Moisture,	·000315900	
Total weight per explosion,	·180222732	
Heat obtained from each explosion,		124·08

HEAT CARRIED OUT EXHAUST FOR 1° DIFFERENCE OF TEMPERATURE.

CO_2,	·0394 × ·2169* = ·0085
O,	·0041 × ·2175 = ·0009
CO,	·0004 × ·2450 = ·0001
H_2O,	·0043 × ·4805 = ·0021
N,	·1317 × ·2438 = ·0321
Moisture,	·0003 × ·4805 = ·0001
	·0438

Difference between temperature of gas and of exhaust = 752°·81 — 74°·68 = 678°·13, and the heat accounted for in the exhaust per explosion = ·0438 × 678°·13 + 4·46† = 34·16, and assuming that the exhaust for those

* *Stewart's Heat*, p. 295.

† Heat of vaporization of H_2O.

times during which no explosion takes place, carries off the same amount of heat, we have

$$34{\cdot}16 \times \frac{160{\cdot}145}{157{\cdot}57} = 34{\cdot}72$$

heat units accounted for in exhaust.

Heat carried away in jacket water, ... = 5988·5 B.T.U. per minute.

Heat carried away per explosion

$$= \frac{5988{\cdot}5}{157{\cdot}57} = 38{\cdot}005 \text{ B.T.U.}$$

Heat per explosion turned into power (indicated),

$$\frac{127{\cdot}7 \times 33{,}000}{157{\cdot}57 \times 778} = 34{,}375 \text{ B.T.U.}$$

Brake H.P. per explosion

$$= \frac{92{\cdot}49}{157{\cdot}57}$$

Heat units equivalents

$$= \frac{92{\cdot}49 \times 33{,}000}{157{\cdot}57 \times 778} = 24{\cdot}889 \text{ B.T.U.}$$

Heat in one pound coal, ... = 14117·818
Heat in equivalent gas, ... = 9756·79, eff. producer 69·1
Heat units available per explosion, = 125·76
Heat units used per explosion, . . = 124·08, eff. explosion 98·7
Heat units for exhaust, ... = 34·721
Heat units for jacket, ... = 38·005
Heat units for power, ... = 34·375
Heat units not accounted for, . . . 16·98
Heat turned into I.H.P., ... = 34·375, eff. of transformation 27·7
Heat turned into B.H.P., ... = 24·889, eff. of machine, 72·4
Eff. of plant, 69·1 × 98·7 × 27·7 × 72·4 = 13·66 per cent.

Coal used per I.H.P. per hour

$$= \frac{3{,}626 \times 60}{127{\cdot}7 \times 1788{\cdot}69} = \mathbf{{\cdot}9511}$$

Coal used per B.H.P. per hour

$$= \frac{3{,}626 \times 60}{92{\cdot}49 \times 1788{\cdot}69} = \mathbf{1{\cdot}315}$$

Combustible used per I.H.P. per hour = ·8729 × ·9511 = **·8302**
Combustible used per B.H.P. per hour = ·8729 × 1·315 = **1·148** +

A large part of the 16·98 heat units not accounted for is partly due to the fact that the pyrometer in the exhaust shows a temperature which is less than the true temperature of the gases because of the short time of the exhaust, and partly to the fact that all the gas from the coal is charged to the engine, whereas part of it was discharged in putting the producer into operation.

The low mechanical efficiency was partly due to the fact that the engine was new, as it had just been completed when it was tested.

The results obtained include all the fuel used during the three days of the test and are therefore a fair indication of the amount of fuel that would be used in actual practice.

RESISTANCE TO SHIP'S MOTION: A NATURAL LAW NEWLY DISCOVERED.

By F. M. F. Cazin.

[*Concluded from p. 310.*]

Vendors of mathematical apparatus have a tool called burette, which is a glass tube, the inner transverse section of which is one centimetre square, this is of a diameter as $1\sqrt{4/\pi} = 1{\cdot}1848$ centimetre.

Then there are marks on the tube beginning at the open end of the tube, the other end being closed by a stop-cock, and these marks are distant the first from the open edge, and one from another just one centimetre, which leaves the inside (volume) spaces between marks to each measure just one cubic centimetre. And of necessity the water contained in the tube between each set of successive marks measuring one cubic centimetre weighs one gramme.

Besides this burette there should be procured three more objects, viz: a solid cylinder of the precise section to fill the tube and when inserted therein to (easily) slide therein without allowing any water to pass between it and the inner wall of the tube, the cylinder being just one centimetre long and in consequence in volume just one cubic

centimetre, and weighing just so many grammes as its specific gravity expresses. And it will do no harm to have two of these, viz: one of a density = 1, which will not sink in the water, and the other one of a higher density, and which in consequence will sink in water.

The fourth object wanted is a vessel deep enough to set the burette upright therein and leave some space above to spare. Otherwise this vessel may be of any width, if only room for water is left around the burette, and, for all we need care for, it might be a pond or the Atlantic Sea itself.

The burette being intended only to assist in judging of or measuring correctly the quantity of medium moving consequent to movement of solid, but not being intended to confine the movement of the medium to within its limits, a series of fine perforations are drilled through the wall of the burette, best on the division lines.

To repeat our experiment we should fasten the burette in an upright position inside the larger vessel, and fill the larger vessel and the burette with water to just level with the top-edge of the burette.

Having provided the described cylinder of higher specific gravity, which we may call "the ebony," with a silk thread to hold or withdraw it by, we should allow it to drop into the burette, filling the same in its transverse section, and we should cause this to take place so slowly, that we may clearly observe what is going on.

The observation will be materialy facilitated, if the water inside of the burette is colored but without increasing its density thereby, and to keep the colored water in the burette, until the free communication between the inside and outside parts of the medium at large is desirable or necessary. In order not to falsify the results, close rubber bands may be used for keeping the perforations through the wall of the burette closed, the removal of which bands from the circular lines of perforations will leave the communication between the inner and outer parts of the medium free.

We assume the upper line (ring) of perforations open, when the ebony is allowed to enter the top of the burette.

As the ebony begins to drop, the colored part of the medium contained so far in the burette passes out through the perforations, and outside of the burette a then visible ascending of parts of the water (medium) takes place to the surface, over which the ascending part at once spreads, until the equilibrium, which was disturbed by the additional volume of the ebony, is re-established.

If the ebony is allowed to drop only to the first mark, this is to remain with its top edge flush with the top edge of the burette, which was in the surface plain of the water, it will be found (the surface being proportionately within the limits of observation), that the surface has risen, just so and the same, as in the case of the steamer launched into a tank or limited harbor basin, where the rise might be also observed and measured.

If the mixing of the different parts of the medium be prevented by a cubic centimetre of oil occupying the upper cubic centimetre of the burette, it would become more clearly visible how the medium, displaced by the ebony, directly ascends to the surface and there spreads. But the critical observer would justly say, that the conditions thereby would lose the necessary similarity or identity, there being a natural tendency to arise to the surface in the oil, entirely independent of the movement of the solid. But there is yet the effect in this case also, which belongs exclusively to the immersing of the solid, viz: that the surface as a totality rises for the precise volume of the ebony.

And with all this the tendency created by lower density in the oil to move in the stated direction is not more powerful than the tendency created in the water pushed out of the way by the bow of the ship to flow continuously to *the* place, when the tendency to re-establish hydrostatic equilibrium dictates, where room is made equally continuously for it in identical quantity behind the ship's stern.

With the ebony occupying the upper cubic centimetre, there is an overflow over the upper edge of the burette and over the water surface in general. But with the ebony withdrawn, this overflow ceases and the original level of

total surface is re-established inside and outside of the burette.

A hollow glass cylinder of the volume and form described for the ebony and of a density = 1 obtained, we may call it the "glass."

This glass will obtain its buoyancy, and being allowed to drop into the burette, as soon as its top face is level with the surface of the water. It is in consequence of this fact, that this glass, when left to sink by its own gravity, will not be overflowed, the same as the ebony was, consequent to the rising of the water, as soon as the lower edge reached the one-centimetre mark, but the upper edge of the glass will project just so far above the top edge of the burette as the surface of the water has risen above its former level.

And it will require the application of power (pressure, weight) to induce the glass to then further sink or fall in the medium, which is incontrovertible proof that there is some labor (mechanical) to be performed in causing the glass (solid) to proceed. If the ebony be substituted, this mechanical labor would be performed by the gravitation of the ebony. And this labor is the object of investigation, because it represents resistance overcome.

In order to establish the actual state of things, as it exists, when ships are floating on the sea, and to have things in a shape that medium moving be easily judged of as to quantity, I propose to then take one gramme or cubic centimetre of water out of the large vessel, which would leave the glass' top face in the same plain with the surface of the water.

With one of the cylinders occupying the upper cubic centimetre of the burette, we have undeniably the total medium with the one cubic centimetre of space within the outlines and limits, as they are set by hydrostatic equilibrium, with no part of the medium filling the space, where the solid glass or ebony is, which we can more readily understand, if we assume the total water (medium) temporarily frozen solid, and the solid cylinder (ebony, glass) removed to show the cavity.

With the second rubber band removed, we may then allow the ebony to proceed (fall) for the distance of one more centimetre (the distance of its own length, measured in the direction of motion *d*). Let us closely observe what is going on, while this movement takes place. Again we observe water (eventually oil) leaving the burette from just in front of the moving ebony.

When the ebony was started, there was a vacant space forming just above (behind) it, but a slight rising of surface taking place, an overflow into the burette at once followed, which filled the vacant space formed by the progress of the ebony within the burette.

With the tendency of motion created by continuous movement in the same direction, the same as by difference in gravity between water and oil, to rise, it would be observed that even the very same drops (molecules) pushed out of the way in front proceed to the rear of the ebony, which would be a truer representation of the actual occurrence under rapid (comparatively) progress (travel) than the slow motion with continuous impulse wanting.

With the ebony (solid) moved for the stated distance we then shall have the following state of affairs. Just one cubic centimetre of the medium (the value *B*, the solid's buoyancy, the volume of the medium equal to the solid's volume) has changed position, from what it occupied previous to the movement of the solid, and the change has been inverse of the direction in which the solid has moved. There has been an interchange of positions in equal volumes between solid and medium.

And with the travel for the second centimetre distance accomplished again, there would be observed a cavity filled with the solid where there was a quantity *B* of the medium before, but this same quantity would be again found in the place where the solid was, before it again moved the distance *d*. And this goes on at the same rate, as the solid advances, the gravitation of the ebony performing the labor of displacing in inverse direction to its fall the stated quantity of the medium. But, if we hold the tube horizontally in the same vessel, the ebony not gravitating, it would move

only in the tube, if pushed, but moving it would cause the same movement of proportionate quantities of the medium in inverse direction to its own movement. The burette served in all this only to aid us in measuring the quantity of medium moving, the connection (with rubber bands removed) being open for the inside and outside parts of the medium to interchange their position, the same as if the tube were not there.

And, indeed, with our observation become keen to the actual state of affairs, we may now repeat the experiment without the burette and with the glass moving right close to the surface horizontally by our application of sufficient pressure for causing it to horizontally move. And in its movement it will truly represent the movement of the ship's immersed part in water at large. That there be more water does not vitiate the movement of its parts. In neither case can the solid proceed without *interchanging* position with measurable quantities of the medium.

THE FALSE THEORY OF EXCLUSIVELY LATERAL DISPLACEMENT.

And it is but proper, that I should show, that the theory of exclusively lateral displacement, as it has been opposed to displacement inverse to motion of solid, is not tenable, when critically examined. I prefer to do this by copying a few passages of my answer to the learned authors of this newest one of all dynamic theories.

The following lines are thus quoted:

"While my theory, based on experimental demonstration, leads to the absolute, ultimate and precise measurement of the effect of movement of the solid in submersion, your criticism culminates in your substituting for my precise equations your own attempt to explain the phenomena under consideration in a manner different from what I believe to have proven. And while you describe your own new theory, you advance no proof of any kind therefor, but claim in its favor self-evidence. Counter-criticism therefore is not applicable, and a simple denial of your unsupported claim alone is called for.

"As human knowlege has advanced, the claim of self-evidence has grown wonderfully less. Nothing is self-evident, that still leaves a reasonable doubt, and the rational doubt is fatal to the claim of self-evidence. And here is one reasonable doubt of many others. Unless you claim under the film claim also a contraction of water to a less volumetric quantity for the same weight, or unless you also claim that the re-establishment of hydrostatic equilibrium partake in the rapidity of lightning—the thickening of films must be visible on either side of a moving ship to the extent of about half the total immersed volume of the ship. And yet the ocean steamer equipped with the propeller screws at proper distance below the surface, and possessing a horizontal section closely adapted to the molecular division lines of the water, produces even at high speed almost no perceptible side-waves. But seamen's practice knows of propeller suction, this is of a velocity of the water next to the ship's sides far in excess of the velocity of the ship herself, this is of a velocity of the water in inverse direction to that in which the ship moves, as a consequence of both ship and water moving relatively in inverse directions.

"Your statement allows of no other conclusion than that displacement of medium has no part whatever in the resistance offered to motion of ship, but that friction, impact, inertia absorb the power that is required to cause movement of ship. While these are names for pretended values in resistance, neither you nor any other theorist or experimenter have stated precise values in kinetic equivalents of energy for these names. I have given real values of ideal precision and clearness. Their validity cannot properly be denied by claiming self-evidence for undefined presumed other values.

"If under your film theory the lateral displacement results, as it then not possibly could otherwise, in the lifting of water sideways above the general level to the full measure of the volume, for which room must be made, you must, in order to uphold the claim, that such continuous lifting of water compensates for itself, also claim that all of the water so raised presses, when on the surface, in no other

direction but against the ship and in the direction of its travel. And this, gentlemen, is contrary to the actual facts, as they are known and daily observable.

"The new theorems, as I presented them for acknowledgment or criticism, have made precise distinction between displacement inversely to the solid's movements on the one hand and lateral displacement on the other, and for either the precise quantities of the medium so displaced have been stated, and proof has been rendered for each. It would have been according to good and respected precedent amongst scientists and with sound logic, gentlemen, if you had controverted these proofs, but you have controverted the conclusions only, and you have done this by advancing without any proof therefor a counter-claim on your part, for which you claim self-evidence, as if your claim were an axiom that humanity were unanimous about.

"It thus appears that you have never truly shown, what I do claim, to be a fallacy, nor the controverting claim you have advanced to be true."

CORRECT APPLICATION OF POWER FOR PRODUCING MOVEMENT OF SHIP.

From the theorems by me advanced, and as I claim also proven, the logical sequence can or must be drawn, that to produce progress of ship, a quantity of water $B/d\ v$ per second must be moved from bow to stern, this is: must be moved continuously in inverse direction to the ship's travel at the rate of $B/d\ .\ v$ kilogrammes per second, and if the power employed for removing this quantity of water is applied in a method and manner directing all force exclusively to the said purpose, then

$$\frac{1}{75} \cdot \frac{B}{d} \cdot v \times \frac{v^2}{2g} \text{ horse-power (metric)}$$

will be sufficient for producing progress of ship with the velocity v, if B is expressed in litres ($= 0{\cdot}1^3{}_m$) or in kilogrammes.

I may illustrate this method of propulsion as follows:

If by some means or other there be created continuously in front of the ship's bow a vacuum, this is: if the water

that is in front of the ship's bow were continuously removed, and if the impulse to fill up the vacuum, in which ship and surrounding water would equally participate, unless either the one or the other possessed such impulse in excess of the other, were increased for the ship, by pressing the same quantity of water, that is removed from in front of the ship's bow, in between the bulk of water and the ship's stern, thus doubling the impulse in the ship to fill the vacuum, as against such possessed by the surrounding water, must not from continuous action as thus specified result continuous progress of ship? And can it be otherwise than that the rate of progress would be proportionate to the quantity of water removed from bow to stern? And what indeed are paddle wheel and propeller screw actually doing in our daily experience?

Therefore continuous displacement of medium in inverse direction to the ship's (solid's) motion is not only the result of all movement in submersion (immersion) but also the most rational method for causing progress of ship.

And it is in the nature of things, that the quantity

$$= \frac{B}{d} \cdot v$$

of water per second need not move in a volume, of which B/d is the transverse section, but that the higher velocity of motion in this water may make up proportionately for reduction in transverse section, and if it takes less power to move this quantity of water on a straight and direct line than on a circuit, then a more effective method of applying propelling power is indicated than the one now practised.

To guide the quantity $B/d \cdot v$ of water per second in the most direct line possible from bow to stern, there should be a longitudinal tube, open to the water at both ends, and therefore not being part of the value B (buoyancy), through which tube the water ($B/d \cdot v$ per second) should be caused to pass in inverse direction to that of the ship's intended travel. And the propeller screw or screws may be located inside of this longitudinal tube or tubes, and the motive-

power may be applied to them, not in their centre but at their circumference. Thus may the most objectionable part of present construction, the cumbersome and unreliable propeller shaft be avoided, and the blades be better protected than they are in present construction. Even the possibility of dispensing with the steam engine entirely and of employing instead, steam jets, directly within such tube or tubes, for propelling the water in inverse direction to the ship's travel, is rationally deserving of serious consideration. And under provision for closing the tubes at their ends, they may be pumped empty, increase the ship's buoyancy, if needed, or the screw may be repaired in open sea. And with provision for giving a direction to the outflowing water at the ship's stern, this water may serve to steer the ship more effectively than it is done with the rudder.

If in addition to the marks for draught the ship's bottom would show marks also for the value B this is for the first displacement including load, the captain might well on the start calculate his speed with the power at his command. And the rating for racing or insurance cannot justly be accomplished, unless it be under consideration of the value B/d, as presented in each case.

For both navigation and nautical construction the following theorems, directly resulting from those already stated, are of importance:

(7) By obliquely advancing the ship increases the resistance to her progress at the precise inverse rate, as she shortens the distance between two perpendiculars on the direction of her motion, leaving the ship between them on the plain of the water's surface.

(8) For the same volume (B) of solid the resistance to motion by the medium increases and decreases at the precise but inverse rate of the solid's length (d) measured (for ships on the water line) in the direction of motion.

(9) By increasing the length of a solid intended to move in submersion (ship-bottom) for a stipulated volume (B), the resistance by the medium to the motion of such solid is decreased at the precise same rate, viz: as the value d increases.

It is by the fundamental fact of measuring resistance to motion of solid in a medium by quantity of medium displaced in inverse direction to the solid's motion, that it has also been possible to establish a universal value for maximal velocity of a solid's fall in a medium as follows:

Maximal velocity of fall in a medium

$$= \sqrt{\delta . d . 2g . \frac{\delta - 1}{\delta + 1}}$$

δ signifying the density of the moving body when compared with the same volume of the medium = 1.

It is thus that I succeeded in building a new system for understanding and for measuring the relation between the matter of stable volume and form, that moves within a fluid or liquid medium and the medium itself.

And a correct measurement of this relation has been effected by ascertaining the fact of movement of medium in inverse direction as the result of the movement of the solid within the medium, and by ascertaining the precise quantity of the medium so moved, which again represents the quantity of solid moving relative to a time unit also.

By mathematical evolution a natural fact observed and acertained has been used to establish natural laws not before known, that relate with equal force and applicability to astronomy, aëronautics, gunnery and even to the railroad train and the use of water-power, indeed to all dynamic relations, as they do to nautics and navigation, because no movement of matter does apparently exist, but it is the movement of matter within matter, within a material medium.

FROM MINE TO FURNACE.

By JOHN BIRKINBINE.
President of the American Institute of Mining Engineers.

[*A lecture delivered before the Franklin Institute, November 14, 1892.*]

[*Concluded from p. 270.*]

While it would be interesting to follow the details of some of the special features of the great producers, it is not practicable in the limited time to do more than call attention to some typical illustrations of mines of different character, or the means employed for their exploitation, and the instances have been selected more with the object of exhibiting prominent features, than as an attempt to cover various details of operation. They are offered to illustrate the peculiarities of mining the different characters of iron ore in various sections of the country.*

During the present year considerable interest has been attracted to the apparently large deposits of iron ore of a satisfactory character, which can be easily mined from what is known as the Mesabi Range, in Minnesota, and this locality is now passing through the developing stages, which have characterized the earlier history of other sections in the Lake Superior regions which have become producers of iron ore.

The pioneers penetrate the forest, generally "packing" their provisions and tools with them, erect a log cabin, and start the preliminary operations with pick, shovel and hand drill, supplemented by hand winch, bucket and pump. If an apparently satisfactory deposit is found, machinery soon takes the place of manual labor, and compressed air is early applied to these enterprises. The necessity of labor saving appliances demands the prompt application of such economies, and not only are power drills introduced in the

* The lecture was illustrated by numerous lantern slides.

early history of most of the mines, but diamond drills are among the implements which may be found at work in the heart of a forest or in the midst of swamps seeking to discover the subterranean secrets. In fact, one who has never visited a newly developing iron region, would be surprised to note how quickly the economies for exploring or exploiting mines, and for transporting the material from them are introduced.

Interesting lessons can be learned by visits to mines in different sections of the country, which are operated to produce the various classes of iron ores. The red hematite mines of the Minnesota Iron Company in Minnesota, the Norrie Mine, the Ashland, the Colby, of the Gogebic Range; the Lake Superior, the Cleveland, the Champion, the Ludington, the Florence and the Penn Iron Mining Company, in the Menominee Range, each possess some quality of interest to the investigator, either by the depth to which the deposit is wrought, sometimes to 1,300 feet; the extent of the underground drifts, the occurrence of ore in the lenses, and in some cases the admixture of magnetite and hematite, all offering interesting themes for study. The Nevada system of timbering, which is liberally employed in the Lake Superior mines, is also in strong contrast with the solid ore columns, 300 feet high, supporting the roof at the magnetite mines at Port Henry, N. Y., and similar though shorter columns at Lyon Mountain, N. Y., and other magnetic mines.

More contrasts are found in the open cut and underground work in different localities; the Tilly Foster mine of magnetite in New York State has become renowned for the efforts there made to secure its dangerous walls, commencing with great arches of brick, sustaining massive braces of concrete, which were placed in rooms which had been worked out, so as to permit removal of pillars, and ending with the blasting away of 500,000 tons of hanging-wall rock, so as to make the work an open cut. On the other hand, the Iron Mountain, Mo., originally wrought as an open cut, is principally exploited by underground workings to remove a mass of detrital ore from the original deposits which had been subsequently covered

by rock of later deposition. The Cornwall ore hills have been wrought open cut until over 12,000,000 tons have been removed from them, an amount nearly four times as great as that won from Iron Mountain, Mo., and there are to-day magnificent faces of this soft magnetite exposed in the hills and railroad cuts passing through the Cornwall property. The mining of the carbonate ore deposits near the Hudson River, N. Y., the winning of the fossil ores in Northern New York, the stripping of sand from the bog deposits of Texas, the handling of the brown hematites of Alabama, Tennessee and other States by steam shovels, all add to the variety of methods and appliances used.

TRANSPORTATION OF IRON ORES AND COAL.

Much of the iron ore from the Lake Superior region, from New York, and some from other States, also large quantities of coal, have to be transported long distances to reach points of consumption, and reshipment is necessary where the transportations are made by both rail and water. An essential of such rehandling and transporting is that it should be done in the least possible time and at small expense, in order to enable the ores to compete with others, which, although not so rich, are found nearer the blast furnaces. As the principal cost of rehandling is for labor, large amounts of money have been expended by different iron and railroad companies for docks and cars built specially for the purpose, so as to bring this item to the lowest point practicable, and also make it possible to handle greater quantities of material than by manual labor. It is now no unusual thing for ore to be taken from the mine in "skips," automatically dumped into specially constructed railroad cars or into ore bins from which it can be discharged into cars, then hauled in these cars to ore docks, where the drop bottoms of the cars are opened and the ore falls into pockets, from which it is run into the hold of the vessel, and in this whole process the only labor necessary is to open the doors of the bins or the bottoms of the railroad cars.

The ore shipping docks on Lakes Superior and Michigan (the largest in the country, if not in the world), in connec-

tion with the ore receiving docks at the lower lake ports (fitted with bridge tramway plants), the railroad cars, and in some cases vessels specially constructed for this purpose, have aided materially in reducing the cost of transporting iron ore to points of consumption. The furnace manager, by means of advanced methods, cheaper or richer iron ores, improved facilities, and larger output, has lessened the cost of pig iron, which in turn has lowered the price of manufactured iron and steel, which has been one of the most important, if not the most important factor in bringing this country up to its present degree of prosperity.

In addition to the seventeen shipping docks erected to handle iron ores from the Lake Superior region, there are others of less magnitude on Lake Champlain, on the Mississippi River, and elsewhere, but the proportions of the docks on Lakes Superior and Michigan and the quantities of ore handled by them are much greater than the others, and the same holds true concerning the ore-receiving docks at lower lake ports, for from this region was obtained 52 per cent. of all the iron ore mined in the United States in 1891.

The ore-shipping docks consist of a wooden structure, built on piles. The top of the dock is from 38 feet to 51 feet 10 inches above the ordinary water level and wide enough to accommodate from two to five lines of railroad tracks. The ore docks have from fifty to 300 pockets, holding from eighty to 170 tons of ore each. The pockets are sheathed with plate iron and slope downward toward the water side of the dock. At the bottom of each pocket is a door which is controlled from the top of the dock. When it is desired to load a vessel, plate-iron chutes, usually semi-circular in form, are lowered into the hatches of the boat, the doors which connect these chutes to the respective pocket are raised, and the ore discharges itself into the hold of the vessel.

Marquette, Mich., is the port from which the first Lake Superior iron ore was sent, and up to the close of the year 1891 there have been loaded into vessels 17,616,880 tons at this port, which in 1891 ranked third, with a shipment of 1,056,027 long tons, all from the Marquette Range.

In 1865, Escanaba, Mich., claimed a share of the shipments from the Marquette Range, this port and Marquette keeping company until 1879, when Escanaba took a liberal lead, chiefly by reason of the development of the Menominee Range, commencing in 1877, and this lead has been continually maintained. In 1891, 3,058,590 long tons, or nearly one-half of the lake shipments, were sent from this port. Of this the Marquette Range contributed 1,154,645 long tons, the Menominee Range 1,480,248 tons, and the Gogebic Range the balance, 423,697 long tons. Since 1865 there has been handled at the Escanaba docks a total of 29,963,257 tons.

The following will indicate how rapidly ore is handled by these docks: One steamer was loaded with 1,659 long tons of iron ore in forty-five minutes; others with 3,027 long tons in three hours, 3,132 long tons in four hours, 2,379 long tons in two hours, 1,927 long tons in two hours, 2,502 long tons in two hours, 1,850 long tons in forty-five minutes. In this last case just one hour elapsed between the arrival of the boat at the dock and its departure. The record for most rapid loading is that of 980 tons, which were run into a steamer in four and three-quarter minutes. The maximum quantity handled at the Escanaba docks into vessels in twenty-four hours was 42,320 long tons

The nearly simultaneous development of the Gogebic iron range in Michigan and Wisconsin and the Vermilion iron range in Minnesota caused the erection of shipping docks, three for the former at Ashland, Wis., and two for the latter at Two Harbors, Minn., both ports making their first shipment in 1884. Ashland, however, soon outstripped its rival and in 1891 ranked second as a shipping port, with 1,261,658 long tons as its output. Since the docks were erected at Ashland in 1884, 7,760,025 tons of ore have been shipped.

In 1891, Two Harbors, Minn., ranked fourth, 890,299 long tons being shipped, and the total from 1884 to the close of 1891 was 4,030,899 long tons. Receiving docks are also projected at Duluth, Minn., to accommodate the anticipated increased shipments from the Mesabi Minnesota mines.

Gladstone, Mich., made its first shipment of ore in 1889, and serves as an additional and competing shipping point for the mines of the Menominee Range. In 1891, 177,866 long tons were shipped.

The length of the seventeen ore-shipping docks, independent of approaches, varies from 400 feet to 1,800 feet. The aggregate of all being 19,342 feet, or (say) three and two-thirds miles. They contain 3,189 pockets, have a total capacity of 385,350 long tons, and cost, approximately, $4,500,000.

In connection with these docks the railroad companies own a total of 12,526 cars, built for use in transporting iron ore, with an aggregate capacity of 187,550 tons of iron ore, their total cost being estimated at $3,600,000.

Six mining companies on Lake Superior own a total of thirty-three vessels, mostly steamships, with an aggregate tonnage of 80,750, especially devoted to the transportation of iron ore, and maintained by the iron-ore producers.

RECEIVING DOCKS.

The bulk of the lake shipments of iron ore are taken to the lower lake ports—Cleveland, Fairport, Ashtabula, Toledo, Sandusky, Huron, Conneaut and Lorain, O.; Erie, Pa., and Buffalo, N. Y., for distribution to the various blast furnaces in Pennsylvania, Ohio, West Virginia, New York, etc. The remaining portion going direct to furnaces situated near to or on the Great Lakes, such as Milwaukee, Wis.; Chicago, Ill.; Detroit, Mich.; Tonawanda, N. Y., and to individual furnaces at various points in Michigan and Wisconsin. Most of the furnaces on the lakes or their estuaries have special appliances for handling iron ore, but it is at the first-mentioned ports on Lake Erie that the larger receiving docks are located, Cleveland having four, Buffalo three, Ashtabula and Fairport two each, and the remaining ports one each.

Two of the receiving docks at Cleveland are each half a mile in length and have a storage width of 350 feet; one at Fairport has a water front of one mile and a width for storage purpose of from 180 to 350 feet. As the ore is stored

in piles from twenty-five to fifty feet in height, the capacity of each of these docks is from 1,000,000 to 1,500,000 long tons, and the average storage capacity of the receiving docks is 300 to 500 tons per foot of water front. During the shipping season, from May to October, the ore is brought to these ports, unloaded, a portion being handled directly to railroad cars and the balance stocked, being shipped to the blast furnaces during the winter months. The largest stock on hand at lake ports in the past nine years was on December 1, 1890, when 3,893,487 long tons were on the docks. The largest stock of ore at the opening of navigation was that on May 1, 1891, when the heavy stocks of the previous year had been reduced to 2,662,223 tons.

Mr. George H. Ely, in a paper, entitled "The Great Lakes of North America,"* gives some some interesting figures in regard to the capital invested in iron ore mining and transportation in the Lake Superior region. The amount of capital invested in the iron ore lands, shipping and receiving docks and their equipment, in railroad cars, vessels, etc., was over $175,000,000.

CONCENTRATION OF IRON ORES.

Considerable interest has for several years been exhibited in the concentration of magnetic iron ores by means of magnetic separators. This is not a novelty, as the United States Patent Office has issued nearly 150 patents (some of them half a century old) for various forms of magnetic separators. The revival of interest in the concentration of lean magnetic iron ores is fortunately at a time when improvements in machinery for reducing in size and handling large quantities of material are supplemented by advanced knowledge of electro-magnetic appliances. The extent to which the process can be applied commercially to many ores, can be decided only after a thorough investigation, embracing the chemical and physical characteristics of the ore, the quantity accessible, the facilities for obtaining it, and the available market for concentrated ore.

* International Congress on Inland Navigation. Paris, 1892.

This method of beneficiating iron ores is confined to magnetite, or possibly to some ores which can by roasting or other process be made sufficiently magnetic to permit of their concentration by the appliances mentioned. Most of the work done has been in enriching lean magnetite, although some ores carrying high percentages of iron have been fed to magnetic separators for the purpose of reducing the amount of phosphorus and sulphur. The predominance of magnetic iron ore in New York and New Jersey, and the existence of large deposits of this class of ore in Pennsylvania and North Carolina, have naturally attracted to these States most of the development in concentrating plants.

There is no question but what the amounts of sulphur, phosphorus, silica, and in some cases titanium, existing in magnetites can generally be considerably reduced if the material is sized and passed through magnetic separators; the degree of perfection reached being influenced by such reduction in size as will actually permit the mechanical separation of the pure magnetite from the other ingredients. In some of the titaniferous iron ores, this element is so combined as to be magnetic, and similarly the sulphur in other ores is in such combination as to make it partially magnetic. It may be possible with improved machinery and greater knowledge to separate various materials from each other, which differ but slightly in magnetism, but present practice is confined to separating magnetic from non-magnetic material, and the results achieved depend largely upon the comminution of the material, the rapidity with which it is fed on the separator and the perfection of the machine.

We may consider the term "concentrates" as applied only to ore which has been comminuted by means of crushing machinery and then passed through water-jigs or magnetic separators to remove materials which lower the grade of the ore.

In jigging, the crushed ore is agitated, water being introduced, which removes the lighter material, while the heavier iron ore sinks and is conveyed from the jig as it is separated. It is in this way that at Lyon Mountain, N. Y.,

the Chateaugay Ore and Iron Company treats the lean magnetite taken from the mines, and a similar method is followed at Iron Mountain, Mo., for the separation of the leaner red hematites.

Magnetic separators have been in use for forty years, but it is only lately that this system has attracted much attention. Although the forms of magnetic separators vary, they may be classed under three general heads:

(1) Altering the trajectory of falling material by introducing the attraction of a magnet, to draw the magnetic portion away from the non-magnetic. Six of this class of machines are now used.

(2) Feeding the ore to a revolving drum or drums, in which is a magnet core, the shells of the drum being either of alternate magnetic and non-magnetic strips, or entirely of magnetic or non-magnetic material. In some of these drums the magnet core is wound so as to exert a constant polarity, in others a series of magnets of alternate polarity compose the core, and in some opposite drums are of opposite polarity. When two drums are used, they are placed so as to revolve toward each other, the ore passing between them, or they are arranged tandem, the drums revolving in the same direction, but sometime at different speeds and with different degrees of magnetic force, so that the ore fed from one drum to the other receives successive treatment. Machines are also arranged with more than two drums. About thirty of this class are in use.

(3) Belt machines in which the ore is fed to a belt or series of belts passing under or over magnets or magnetic drums, the machines working sometimes in water and sometimes dry. In some of the machines the polarity is maintained continuously by means of pole pieces, in others the material is constantly submitted to magnets of alternate polarity, the belts being placed so as to run either vertically, horizontally, or on an incline, according as the conditions require. There are between twenty-five and thirty of this class now at work.

These separators are used either at the mines to enrich the ore, at steel works and rolling mills to remove the

magnetic particles from slag and dirt, to separate iron ore from pottery clay or from emery—and in one instance iron ore occurring as a hematite with zinc ore is treated in a roasting furnace after being comminuted, and becoming magnetic, can be thus separated.

There is apparently a present field for magnetic separation in the States of New York, New Jersey, Pennsylvania, Virginia, North Carolina and Michigan, where there are large deposits of lean magnetic ores. The prejudice against the use of concentrated ore by some blast furnace managers has been largely overcome by practice, which has proven that properly concentrated ore contributes to the good working of the furnace, and in the future this class of ore may be used largely in place of some of the higher-priced ore brought to Eastern blast furnaces. This class of ore has also been used in most of the direct processes, and any development of these will encourage a corresponding demand for concentrates.

During the year 1891 there were produced 16,802 long tons of hand-picked or cobbed ore, 98,546 long tons of magnetically separated ore, and 110,777 long tons of jigged ore.

CONCLUSION.

In presenting for your consideration the subject of this evening, I have relied mainly upon the eye, believing that in this way it would be possible to convey more information concerning typical features in an attractive manner than to weary you with theories and detailed statistics. Most of the time has been devoted to iron ore, because nearly all that we use or import is smelted to produce pig iron, and but a portion of the coal mined or limestone quarried enters into the production of iron. But the small attention given the fuel and flux must not be considered as a gauge of their importance. The mining and quarrying, the preparation, the handling of the raw materials entering into the manufacture of pig iron supplies work for an army of laborers, miners, mechanics, railroad men, sailors, clerks, engineers, superintendents and managers, and demands the investment of many millions of capital.

OBITUARY.

EUGENE NUGENT.

EUGENE NUGENT, one of the oldest members of the Franklin Institute, died on February 28, 1893, at the Washington Hotel, Philadelphia, where he had resided for a number of years. While the deceased at no time took a prominent or active part in the affairs of the Institute, he was for years a regular attendant at its meetings and lectures, and a constant occupant of its reading-room, and his associates will miss his familiar figure from its accustomed place. Mr. Nugent was born in Germantown (Philadelphia) in the year 1805, and was engaged in various business pursuits in his native city and in Louisville, Ky., until about the year 1867, when he retired from active business. He was of an extremely retiring disposition, and his surviving business associates speak in the highest terms of his probity and scrupulous fidelity to duty.

The deceased never married. At his request, his body was cremated, and his ashes now rest in Laurel Hill Cemetery. W.

PROCEEDINGS

OF THE

CHEMICAL SECTION

OF THE

FRANKLIN INSTITUTE.

[*Stated meeting, held Tuesday, April 18, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, April 18, 1892.

DR. WM. H. GREENE, President, in the chair.

The Section met at the usual hour. A number of bills, for subscriptions to journals and expenses incurred by the Actuary in mailing the Section's notices and papers, were approved for payment.

An interesting paper, by Dr. Edgar F. Smith and Mr. Vickers Oberholtzer, on "The Action of the Haloid Acids in Gas Form upon Molybdic Acid," was read by Dr. Smith, and was referred for publication.

Adjourned. H. PEMBERTON, JR., *Secretary pro tem.*

PROCEEDINGS

OF THE

ELECTRICAL SECTION

OF THE

FRANKLIN INSTITUTE.

[*Stated meeting, held Tuesday, March 28, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 28, 1893.

MR. E. G. WILLYOUNG, President, in the chair.

The stated meeting of the Section held on this date, was called to order by President Willyoung, at 8.10 P.M.

Present, thirty-four members and visitors.

The minutes of the previous meeting were read and approved.

The Treasurer reported a cash balance of $59.92 in the treasury, and presented bills for printing amounting to $35.51, which were ordered paid.

On behalf of the special committee appointed at the last meeting for the entertainment of members at this meeting, Mr. C. W. Pike stated that arrangements had been made for an informal lunch to be held at Reisser's restaurant, at the close of the evening's exercises.

Upon suggestion by Dr. Wahl, the Secretary was instructed to send a list of associate, corresponding and honorary members of the Section to the Actuary of the Institute.

Owing to an engagement, Prof. Houston's paper, on "Chas. A. Coulomb and his Work," was given first place on the programme.

It was an interesting memoir, and evoked quite a discussion concerning the correctness of some of Coulomb's discoveries, as viewed in the light of present knowledge.

The paper was referred for publication.

"The Migration of the Ions," by Prof. Geo. F. Stradling, was a *résumé* of researches by Hittorf and Kohlrausch on the velocity of various ions in solutions of varying degrees of density. This was followed by a paper by Mr. C. Billberg, on "A Simple Method for Increasing the Output of Dynamos and Motors." This method is to use iron for the binding wire of the armature instead of non-magnetic alloys.

Mr. Carl Hering pointed out the fact that Dobrowlsky made use of an iron ring inside the pole pieces, which diminished the sparking and allowed the shifting of the brushes to the position of greatest difference of potential, thus increasing the output.

Mr. Winand pointed out the distinction between Dobrowlsky's method and that of Mr. Billberg.

It was moved that further discussion on the papers of Prof. Stradling and Mr. Billberg be postponed till the next meeting, and that the papers be printed and sent out as soon as possible.

The meeting then adjourned. R. H. LAIRD, *Secretary.*

THE MIGRATION OF THE IONS.

BY GEORGE FLOWERS STRADLING.

[*Read at the stated meeting of the Electrical Section, March 28, 1893.*]

For almost a century the passage of an electric current through an electrolyte has been attributed to direct transportation of the electricity by the ions resulting from the decomposition brought about by the current. The changes and improvements imparted to the crude theory of Grotthuss by Williamson and Clausius, and more recently by Svante Arrhenius, have not altered this explanation. Upon the startling, yet apparently correct, theory of Arrhenius, the reasoning which will subsequently be used might be based; but, as Grotthuss' simpler hypothesis lends itself more readily to explanation, it will be employed.

Suppose we are electrolyzing a dilute solution of sulphuric acid. The hydrogen goes with the current and appears at the kathode; the radical SO_4 moves against the current, and, but for secondary action, would appear at the anode. Each ion moves through the liquid, but with what velocity? Shall it be assumed that the velocity is the same for both ions? One thing that will go far toward determining the velocity is the friction of the moving atoms against their environment. As the hydrogen atom makes its way toward the kathode, it will come in contact with other hydrogen atoms and with the liquid in which the acid is dissolved, perhaps also with SO_4 groups moving in the opposite direction. The same thing is true of the other ion. Now, the two ions are, of course, quite different in nature, and the resistance which they will experience will, in general, be different. Hence, in general, their velocities will be different.

So much for the antecedent probabilities of the case. In order to put this reasoning to the test, it will be necessary to deduce results that must follow were the velocities the same, and others which must follow, if they are different, and then, by experiment, to determine which deductions are supported by facts.

Let the diagrams (*Fig. 1*) represent in a general way electrolysis upon the supposition that the ions move with equal velocities in opposite directions. *AB* represents an imaginary partition, so situated in the liquid that any changes in concentration arising at the electrodes will not affect the electrolyte in its vicinity. The positive and negative ions,

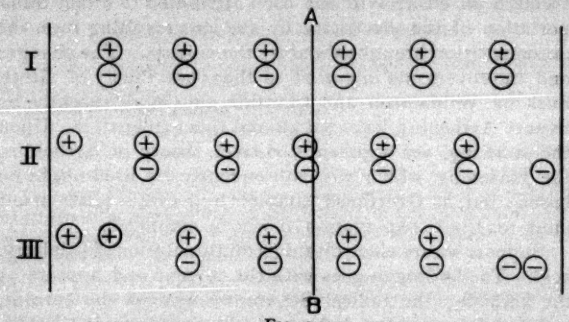


FIG. 1.

united in the molecules of the substance being electrolyzed, are represented by circles having + and — signs, respectively. *Diagram I* represents the position of the ions before the passage of the current. In *Diagram II*, the current has passed long enough to move each positive ion to the left and each negative one to the right, through an equal distance, that distance being just enough to cause the liberation at the electrodes of one atom of each ion. In *Diagram III*, two atoms of each ion are set free, and two molecules of the electrolytic substance have been broken up.

In *I*, there were three positive and three negative atoms on each side of the partition *AB*. In *III*, to the left of *AB* there are four positive atoms, and to the right four negative

ones. Thus the gain of positive atoms to the left equals the gain of negative ones to the right. If now the entire quantity of the positive ion to the left of *AB* be found, including both the amount in the liquid and that set free at the kathode, and the gain over the amount present before the passage of the current be compared with the amount liberated at the kathode, the ratio is seen to be one-half, which is the same for the negative ion to the right of *AB*. The determination of the amount of the two ions present in the liquid can be made by chemical analysis, and thus

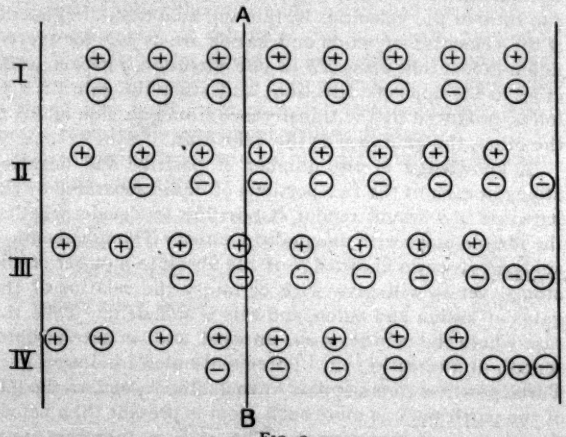


FIG. 2.

the tenability of the supposition of equal velocities be examined. If it is found that to the left of *AB* there is, after the passage of a current, a gain of the positive ion equal to one-half of the quantity set free at the kathode, and that the ratio holds true for the negative ion also, then, and only then, will it be shown that the ions have equal velocities.

In *Fig. 2* the positive ion moves to the left with but half the velocity with which the negative one moves to the right. *AB* has the same meaning as before; *I* represents

the conditions before the passage of the current; *II*, *III* and *IV* show the state after the electrolysis of one, two and three molecules. Before the passage of the current, there are three positive atoms to the left and five to the right of *AB*, and, of course, the same number of negative ones. After three molecules have been dissociated, we find four positive atoms to the left and seven negative ones to the right; a gain of one positive atom and of two negative atoms on the respective sides. It will be noticed that the gains are as 1 : 2, in the same ratio as the velocities. A little consideration will show that, in every case, no matter what the ratio of the velocities is, this will hold true. In general, if the velocities of anion and kation are as $p:q$, for every p anion atoms that cross *AB* in one direction, q kation atoms cross in the opposite direction; and, since the gain of each ion is produced by the transference from one side of *AB* to the other, the gains are as the velocities.

A knowledge of the number of positive and negative atoms in each of the two portions of liquid separated by the partition *AB* would render it possible to decide whether the ions do move with unequal velocities. Though chemical analysis gives no knowledge of the absolute number of the atoms, yet it will give with certainty the relation of the gains of kation and anion, and this is sufficient. Take the case where the velocities are unequal, and, as above represented, in the ratio 1 : 2. Three molecules are dissociated. Three positive atoms appear at the kathode, and, to the left of the partition, one more such atom is present than before the passage of the current. The gain is, therefore, one-third of the quantity set free. Two negative atoms are gained on the right side, two-thirds of the quantity set free. If, then, we know how much of the positive ion is present to the left of the partition at the beginning of the experiment, how much at the end, and how much is liberated or deposited at the kathode, the velocity of the positive ion is proportional to the amount gained divided by the amount liberated or deposited. In getting the amount present after the passage of the current, both that in the liquid and that set free at the kathode are to be taken into account.

The same procedure carried out for the anion, of course, gives a fraction to which its velocity is proportional, and the sum of this fraction and that obtained for the kation is unity. It is manifestly not necessary to carry out the analysis for both ions, for, having found one fraction, the other is found by subtracting the first from unity. For instance, if it is found that the gain of the kation to the left of the partition is two grammes, and the amount liberated is five grammes, then the velocity of the kation is as two-fifths, and the velocity of the anion as $1 - \frac{2}{5}$ or $\frac{3}{5}$. The velocities are here as $\frac{2}{5} : \frac{3}{5}$ or $2 : 3$.

Hittorf* applied the reasoning which has been given to the determination of the velocities of a good number of ions. To collect the liquid on one side of an imaginary partition for analysis is no easy matter, but he succeeded in doing this with great skill, and obtained results which show a remarkable agreement with each other.

The following is an example of how the relative velocities were found for $CuSO_4$.

	Grammes.
Quantity of Cu liberated at kathode,	·3161
Decrease of Cu in solution on kathode side,	·2288
Net gain of Cu,	·0873
Ratio of gain to deposit, $\frac{873}{3161} =$	·276

Hence, vel. of Cu : vel. of SO_4 :: 276 : 724.

A table of Hittorf's results is to be found in vol ii, *Wiedemann's Electricität*, from which those below are taken:

Substance.	*H_2O to 1 Gramme. Substance.*	Velocities. *Kation.*	*Anion.*
NaCl,	3·47	·352	·648
	20·70	·366	·634
	104·76	·372	·628
	320·33	·383	·617
Na_2SO_4,	11·77	·359	·641
$NaNO_3$,	2·99	·400	·600
KCl,	4·84	·484	·516
K_2SO_4,	11·84	·500	·500
KNO_3,	4·62	·521	·479
HCl,	2·90	·661	·339

* *Vide Pogg. Ann.*, lxxxix, xcviii, ciii, civ and cvi.

Two changes might affect the relation of the velocity of the kation to that of the anion alteration of current strength and of concentration. Both were investigated by Hittorf. He found that the relative velocities are independent of the current strength.

For a solution of $CuSO_4$;

Intensity of Current.	*Velocity of Kation.*
113	·291
420	·285
958	·289

On the other hand, concentration does have a very decided influence. An instance of this may be seen in the case of NaCl, in the table given above. For $CuSO_4$ the following results were obtained:

	Velocity of Cu.
One part $CuSO_4$ to 6·35 H_2O.	·276
9·56	·288
18·08	·325
39·67	·355
76·88	·349
148·3	·362

There is, however, no reason to suppose that, in general, the effect of dilution would be to increase the velocity of the kation rather than that of the anion.

For twenty years after the publication of Hittorf's results upon the relative velocities of the ions, so far as the writer knows, no one made use of them in any way to get the absolute velocities. This was left for Friedrich Kohlrausch to accomplish.*

Think now of an atom of an ion moving in a dilute solution. Its friction is chiefly against the solvent, and but little against the other constituent of the salt in solution. It will then probably make but little difference what that other constituent is. The atom will probably move with a velocity not at all dependent upon the other atom from which it has been separated. In other words, it seems likely that in dilute solutions each ion moves with a velocity peculiar to itself and to the solvent, and not depending

* *Wied. Ann.*, vi, 160.

upon the salt from which it has come. Kohlrausch drew from his wide-reaching observations on the conductivity of dilute solutions data which show that such is really the case.

Suppose we have a portion of an electrolyte one centimetre long and one square centimetre in cross-section. Let its conductivity be k, the velocity of the kation be u, and of the anion v.

Let the cubic centimetre contain as much of the salt to be electrolyzed as would be formed by the union of that quantity of the positive ion which will convey m units of positive electricity to the kathode with the amount of the negative ion which will carry the same amount of negative electricity to the anode. One volt electro-motive force will be supposed to exist between the ends of the liquid column.

By Ohm's law—

$$C = \frac{E}{R} = E \cdot K, \text{ or as } E = 1, C = K. \qquad (1)$$

It is also possible to express the current strength in terms of u and v. There are m units of positive electricity moving toward the kathode with the velocity u, and an equal quantity of negative moving in the opposite direction with the velocity v. This is equivalent to m units of positive electricity moving to the kathode with the velocity $u + v$. In one second, then, $m(u + v)$ units of positive electricity would pass through any cross-section of the liquid column, and this is accordingly another expression for the current strength.

$$C = m(u + v) \qquad (2)$$

From (1) and (2) we get

$$K = m(u + v) \qquad (3)$$

From his experiments, Kohlrausch found the quantity by which m must be multiplied in order to get the conductivity. By comparison with (3) it is seen that this quantity must equal the sum of u and v. From Hittorf we get the ratios of u and v, and from Kohlrausch their sum, and from

the two relations the absolute values of u and v are readily obtained.

The following results, in which numbers proportional to u and v are given, show how near to the truth is the supposition that the velocity of an ion in a dilute solution is independent of the salt from which it is separated:

	From Chloride.	*Iodide.*	*Nitrate.*	*Acetate.*
K,	$u = 48$	51	46	47
Na,	$u = 31$	34	29	31
	Cl.	*I.*	NO_3.	$C_2H_3O_2$.
From potassium salts,	$v = 50$	52	45	23
sodium salts,	$v = 51$	51	46	23

In the table which follows, in addition to the absolute velocities of the ions, there is given the force in gravitation units which must act upon one milligramme of the ion to give it a velocity of one millimetre per second. These forces are very large, but Kohlrausch shows that they are of the same order of magnitude as the forces necessary to overcome the friction between such exceedingly small portions of matter as atoms (in which the ratio of surface to mass is very great) and the liquid solvent. The velocities are those which would be produced in a column of liquid one millimetre long, with a difference of potential of one volt at the ends.

Ion.	Vel. mm. per sec.	Kgm.	Ion.	Vel. mm. per sec.	Kgm.
With Monobasic Acids.			CN,	·054	7,000
			NO_3,	·049	2,200
H,	·300	32,500	ClO_3,	·043	2,700
K,	·052	4,800	$C_2H_3O_2$,	·025	6,700
NH_4,	·050	10,800			
Na,	·034	12,500	*With Dibasic Acids.*		
Li,	·022	61,600			
Ag,	·043	2,100	H_2,	·179	54,500
Cl,	·053	5,200	K_2,	·043	5,800
Br,	·027	9,200	$(NH_4)_2$,	·039	13,700
I,	·027	9,300	Na_2,	·024	17,800
Fl,	·032	16,000	Li_2,	·019	113,000
½ Ba,	·031	4,500	Ag_2,	·034	2,600
½ Sr,	·030	7,300	SO_4,	·043	4,700
½ Ca,	·028	17,700	CO_3,	·039	8,300
½ Mg,	·025	33,000	*With SO_4.*		
½ Zn,	·027	13,000			
½ Cu,	·031	9,800	Mg,	·015	54,000
			Zn,	·013	23,000
			Cu,	·013	24,000
			SO_4,	·024	8,600

When the solution is not dilute, the question of friction becomes a more complicated one, and the ratios of u and v change with the concentration.

m.	u.	v.	
0	·179	·043	for H_2SO_4.
1	·166	·034	
2	·153	·031	
4	·125	·027	
8	·071	·022	

Oliver Lodge has actually observed the velocity of the passage of hydrogen. It moved through a tube filled with sodium chloride dissolved in jelly, decolorizing phenolphthalein as it went. He found the velocity to be ·29 millimetres per second, whereas the calculation of Kohlrausch gave the closely agreeing result ·30.

In November of 1892, J. J. Thomson brought before the Royal Society an account of experiments conducted by Mr. W. C. Dampier Whetham upon the velocity of certain ions. A current was sent through a tube containing $CuCl_2$ and NH_4Cl. The boundary was distinct and its rate of motion could be accurately measured.

	Observed.	*Calculated.*
Vel. of Cu,	·0309	·031
Cl,	057	·053
Cr_2O_7,	·047	·0473

It is seen by a comparison of observation with calculation that they lead to almost identical conclusions respecting the absolute velocities of the ions. It is therefore safe to assume that the suppositions which underlie the calculated results are in the main correct.

Northeast Manual Training
High School, Philadelphia.

SOME PRINCIPLES THAT MUST BE OBSERVED IN ORDER TO MAKE A GOOD CLOSED-CIRCUIT BATTERY, AND A NEW PORTABLE DRY CELL DESCRIBED IN WHICH THESE PRINCIPLES ARE APPLIED.

BY E. F. NORTHRUP.

[*A paper read before the Electrical Section, Dec. 28, 1892; Jan. 24, 1893.*]

[*Concluded from p. 323.*]

Some careful tests were made of the life of different cells, usually by determining the total number of coulombs that they could furnish. This test was conducted by running the cells connected in series through a copper voltameter until they were completely exhausted. Some resistance was usually placed in the circuit to prevent too rapid action. The life of a Barrett silver chloride cell tested in this way proved to be 2,473 coulombs or nearly $\frac{68}{100}$ of an ampère hour. The average total current supplied by one of the smallest size iodine cells described above (see *Fig. 1*), in which the depolarizer was sulphur iodide, was ·21 of an ampère hour. This, considering the small size of the cell, is a very high efficiency and it might be increased somewhat if desired by using a larger proportion of the depolarizer. The iodine and mercury oxide depolarizer gives even a higher efficiency than this. A similar test was made upon a larger size iodine cell, which had a volume of 1·1 cubic inch, and the form slightly modified, as shown in *Figs. 2* and *3*. This furnished 2,295 coulombs or ·64 of an ampère hour. As these cells are only intended for test work very little current is taken from them. Assuming that the average resistance used in the entire circuit of a resistance set is 1,000 ohms, and that forty volts are used and that the duration of each closure of the key is one second, 17,500 taps would be required to exhaust one of the smallest cells and 57,375 to exhaust one of the larger ones. Thus for the purpose to which these cells are adapted their life is very long.

Of course, this same combination of materials might be used in cells of various forms and any size. A cell, constructed as shown in *Fig. 2*, which is $\frac{5}{8}$ x $2\frac{1}{2}$ inches, will have

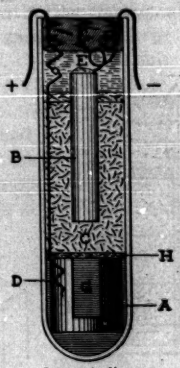


FIG. 2.—Large iodine test cell.

A = carbon electrode shown in perspective in *Fig. 3*.
B = zinc electrode.
C = paste, same as in other cells.
D = platinum fine wire.
E = viscous seal.
F = plaster Paris seal.
G = depolorizer, either I_4S_3 or $HgO + I$.
H = partition of asbestos cloth.

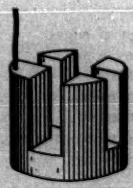


FIG. 3.—Perspective view of carbon electrode used in larger form of test cell.

under thirty ohms internal resistance and will furnish through fourteen ohms external resistence about thirty to forty milliampères; so this style of cell may also be used with advantage where current rather than electro-motive force is

required. Other forms, however, were devised for this purpose. *Fig. 4* shows a cell with a square case, $1\frac{1}{2} \times 2\frac{3}{4}$ inches, which is especially adapted for running physicians' induction coils. The depolarizer, which may be either I_2S_2 or HgO + I, is placed in the partitions of a box-like carbon

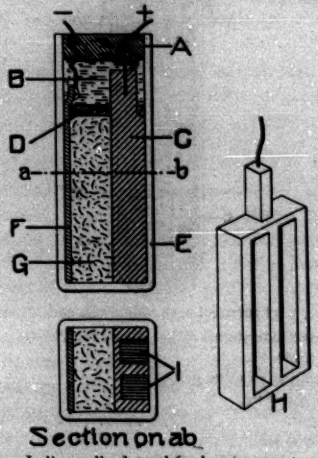


FIG. 4.—Iodine cell adapted for large current output.

A = plaster Paris or cement seal.
B = viscous seal.
C = carbon electrode (view of edge).
D = cork to hold electrodes in place.
E = containing case of glass.
F = zinc electrode (view of edge).
G = paste (same as in test cells).
H = perspective view of porous carbon electrode.
I = depolarizer, either I_2S_2 or HgO + I.

electrode, the open side of which is placed against the side of the glass case. The carbon electrode is thus seen to serve also the purpose of a porous cup. This general principle of having the depolarizer behind or inside of a porous carbon electrode, so that the current does not have to pass through a substance of high resistance, is one which seems

capable of valuable developments. Experiments are now being continued along this line aiming towards the construction of a large powerful battery for cautery work, running of motors and other purposes where great efficiency combined with transportability is required, and it is hoped that results will soon be forthcoming.

Some very exhaustive experiments were made, using free bromine for a depolarizer. But this in an unmixed or uncombined state had to be finally abandoned, as the bromine diffused through the electrolyte and caused the cell, whether kept on open or closed circuit, to give out in about a month. The device was finally adopted of dissolv-

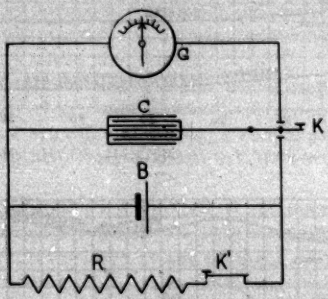


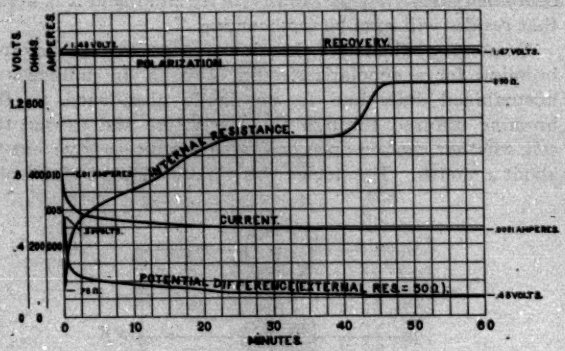
FIG. 5.

ing the bromine in carbon disulphide. This practically prevents diffusion of the bromine, but does not seem to affect its qualities as a depolarizer when used with a porous carbon electrode like the one described and shown in *Fig. 3*. The combination gives about 1·8 volts. It is hoped that these cells are free from defects, but the important test of time must be given to them before this can be positively asserted.

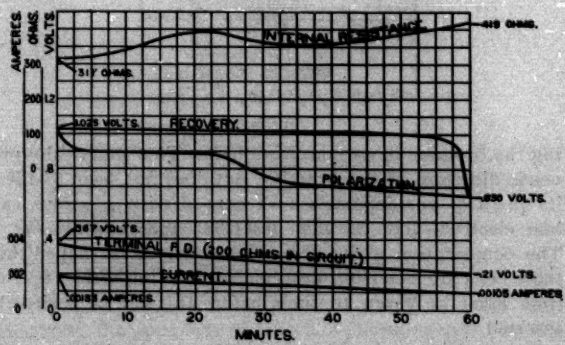
The complete record of the action of a battery is given by curves which represent their polarization, recovery, internal resistance, terminal potential difference and current. The method adopted for obtaining these curves is fully described in Prof. H. S. Carhart's work on primary batteries.

It may be called the condenser method and briefly stated is as follows:

In the diagram, *Fig. 5*, *G* is a ballistic galvanometer, *C* a condenser, *B* a cell, *R* a resistance, the fall of potential over



CURVES No. 1.—Curves of a $Zn/MgCl_2/Hg_2SO_4/Hg$ cell. Size, 2 x ¾ ins.



CURVES No. 2.—Curves of a $Zn/ZnCl_2/CuO/Cu$ cell.

which is to be measured; *K'* a key to put this resistance in circuit with the battery *B*, and *K* a double key for charging the condenser and discharging it through the galvanometer.

The condenser is first charged (K' being open) by means of a Carhart-Clark standard cell, then discharged and the galvanometer deflection read by means of a telescope and scale. The standard is then replaced by the battery to be tested. With K' open, the condenser is charged and discharged as before. Then K' is olosed and after an interval of one minute the condenser is again charged and discharged. K' is now kept closed for an hour, except at intervals of two minutes, when it is opened just long enough to charge and discharge the condenser, and readings are taken which give the potential of the cell on open circuit. The condenser is also charged and discharged, K' being kept closed, at intervals alternating with the open circuit readings. At the end of the hour K' is opened permanently and open circuit readings are taken at intervals of one minute or longer. In this way the recovery curve is obtained.

The deflection of the standard and its electro-motive force being known, the electro-motive forces corresponding to the other deflections are calculated from a simple proportion or more easily read off from a straight line curve, which is readily drawn.

The internal resistance of the cell at any moment during the hour is obtained as follows: Call the electro-motive force of the open circuit readings at any moment E, that of the closed circuit reading at the same moment, which is the fall of the potential over the resistance, R, E', then, if r is the internal resistance sought, we can make the following equations: There is a total potential of E, there is a fall of potential over the external resistance E'. Therefore, there must be a fall of potenial $E - E'$ over the internal resistance, hence $r : R :: E - E' : E$ or

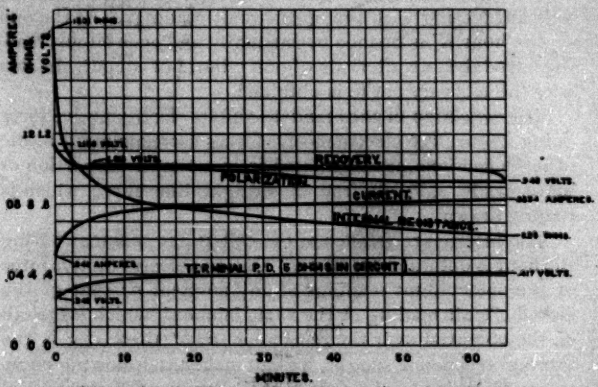
$$r = \frac{E - E'}{E'} R$$

After the polarization curve given by the different electro-motive forces called E, and the terminal potential difference curve given by the electro-motive forces called E' are plotted, then the data for solving the equations giving the points for the internal resistance curves can be read off on

the ordinates directly. The current flowing at any time is, simply,

$$C = \frac{E'}{R}$$

If in addition to this test a battery is run completely out through a voltameter, and the number of coulombs that it will furnish be calculated, and, if further, after being used some it is laid away for a few months to test if any destructive local action goes on, then, if all these tests are favorable, the battery may be pronounced a good one, and not with certainty before.



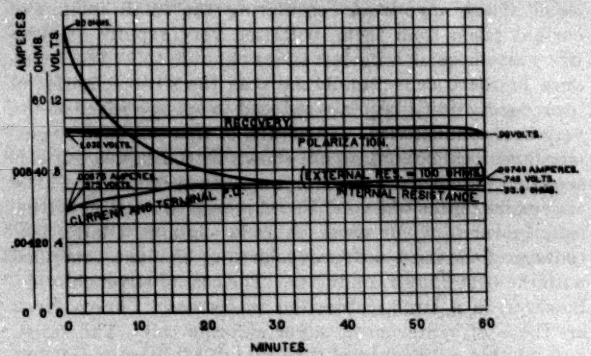
CURVES No. 3.—Curves of the Barrett silver chloride cell.

There are very few of the "wonderful" dry cells advertised which will bear such an exposure as the above tests will give them, and unless the manufacturers of cells claimed to be perfection are willing to submit their goods to such tests their honesty will at least bear examination.

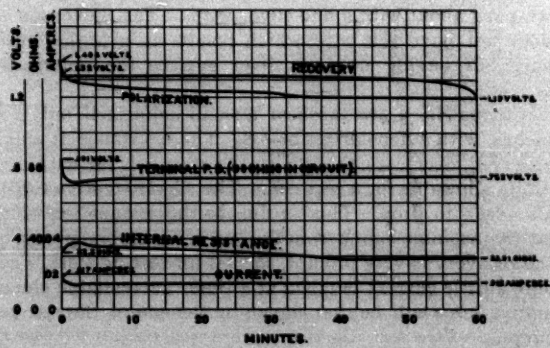
The following curves of some dry cells made by various parties and characteristic of different types of depolarizers are given for reference. These cells do not differ much in size from the iodine cell shown in *Fig. 2*:

Curves No. 1 represent the action of a $Zn/MgCl_2/Hg_2SO_4/Hg$ cell constructed upon the same general plan as the

iodine cell in *Fig. 2*. The Hg_2SO_4 is a solid depolarizer and the cell has a very high resistance, which runs up rapidly. The electro-motive force of this combination is the highest



CURVES NO. 4.—Curves of the Stevenson silver chloride cell, same size as Barrett cell. Size of cell itself without protecting case is 2¾ x ¾ inches.



CURVES NO. 5.—Curves of small iodine test cell. Size, 2 x ½ inches. Depolarizer, sulphur iodide (I_4S_4).

that can be obtained in a closed cell in which a metal is used for the negative electrode, which is depolarized by a salt that is reduced to this metal, unless use be made of the

rarer elements. Curves No. 2 are those of a cell with CuO for a depolarizer and a paste made of red oxide of iron. These cells also are valueless on account of their high resistance. They have also, considering the small amount of current taken from them, polarized very rapidly. Curves No. 3 are those of a Barrett silver chloride cell. The resistance of these cells rapidly falls as the silver chloride of poor conductivity becomes reduced to spongy silver of the very best conductivity. The faults of this cell, such as gassing and local action, are not shown by the curves, but it is seen that the electro-motive force is on an average only a little above nine-tenths of a volt. The curves of this cell, nevertheless, are very fine, for silver chloride contains a large percentage of the most active depolarizing element, combined with the best known conductor. The cost of silver chloride, however, is a strong objection to its use. Curves No. 4 are those of a Stevenson silver chloride cell. The resistance of this cell is greater than that of the Barrett cell, but it has polarized less. The low resistance of the Barrett is due to the fact that the poorly conducting silver chloride is wrapped about with a fine silver wire. The Stevenson cell does not have this wire, which results in a higher resistance, but having no free silver surface the polarization is less.

Curves No. 5 are those of a small iodine cell, only $2 \times \frac{1}{2}$ inches, with a depolarizer of I_2S_2. The resistance, it will be observed, decreases, though at the start it is far within the limits allowable for a test cell. The electro-motive force is also seen to drop. This is due to the exhaustion of the nearly insoluble iodine from the end of the carbon prong, but the recovery is very prompt, so that for testing work, where only a little current is taken at a time, the available electro-motive force will be that shown by the end of the recovery curve.

For purposes where much steady current is required the size and form of these cells will be like that indicated in *Fig. 4*. Curves of this latter form have not yet been obtained, but several tests have been made by running them completely out on a milliampère meter and upon induction coils which

have proved their very high efficiency. With HgO united to I their available electro-motive force is about 1·4 volts and their internal resistance between one and three ohms, and their total output greater than the silver chloride cells described.

The battery problem is not an electrical one merely. It is chiefly a chemical and mechanical question and one which a person with only an electrical knowledge can scarcely hope to undertake with success. There are many improvements yet to be made in primary cells, and those who take the work up should bear in mind that a good battery, like anything that is at all complicated, cannot be stumbled upon, but must be laboriously and logically studied out, and then proved by careful experimenting to be of sterling value.

Franklin Institute

[*Proceedings of the stated meeting, held Wednesday, April 19, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, April 19, 1893

JOSEPH M. WILSON, President, in the chair.

Present, seventy-eight members and fourteen visitors.

Additions to membership since last report, eight.

The Secretary reported the resignation of Mr. John Hall from membership in the Committee on Science and the Arts. The resignation was accepted, and the meeting proceeded to fill this vacancy and the two others held over from the previous month, by election.

The result of the vote was the election of Mr. C. L. Prince for the unexpired term of Mr. Pistor; Mr. Henry Brinton for the unexpired term of Mr. McAllister; Mr. W. N. Jennings for the unexpired term of Mr. Hall.

Mr. John Hartman exhibited a series of handsome lantern views, representing the most notable specimens of ancient Egyptian architecture, and made some critical observations and comments upon their architectural and mechanical features. (To be published in abstract.)

Mr. George F. Simonds, of Fitchburg, Mass., read a paper on the manufacture of anti-friction ball-bearings, describing a system and apparatus which he had invented for this purpose. The speaker illustrated the subject by the exhibition of a number of specimens, large and small, provided with his improved journal bearings. He also showed examples of hardened

steel spheres of $\frac{1}{32}$″ and $\frac{1}{64}$″ diameter, claimed to vary from perfect spheres by less than the $\frac{1}{10000}$ of an inch; and a collapsing mandrel devised by himself and used in his method of insuring absolute uniformity in the dimensions of the hardened sleeves employed in the production of his improved bearings. (Mr. Simonds' paper is referred for publication.)

Mr. James G. Satterthwait read a paper, briefly reviewing the history and development of the applications of electricity for heating purposes, and at the close of the meeting exhibited and showed in operation a large number of domestic heating appliances, of the Carpenter type, offered for inspection by Messrs. Walker & Keppler, of Philadelphia.

The Secretary read an official communication from Mr. S. Lloyd Wiegand, Trustee of the Elliott Cresson Medal Fund, notifying the Institute of the fact that a vacancy existed in the trust by reason of the resignation of Mr. Samuel Sartain, as a trustee, and, that in accordance with the terms of the deed of trust, the said vacancy must be filled by election, at the next succeeding stated meeting of the Institute after the receipt of this notice.

A communication from a special committee of the American Philosophical Society was presented, announcing the fact that "the Society will celebrate the one hundred and fiftieth anniversary of its foundation by a series of reunions at the Hall of the Society, during the week beginning Monday, May 22, 1893, terminating on Friday, May 26, 1893, at which papers may be offered by title by such delegates as may honor the Society with their presence." The communication concluded with the statement that the Society will be pleased to receive a delegate from the Institute.

The President was authorized by vote to name a delegate to participate in the proposed reunions.

A communication was presented from "The Committee of Fifty for a New Philadelphia," asking the Institute to appoint three delegates to represent the Institute in a "Union Committee," to be composed of delegates from the various organizations of citizens interested in public work, with the object of promoting needful municipal improvements. The President was authorized to name three delegates to represent the Institute in the committee, in the manner requested.

The meeting then adjourned.

WM. H. WAHL,
Secretary.